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Environmental Protection Agency, Washington, D.C.

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Working Group
on the Prevention of
Water Pollution
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Industrial Sources

Cincinnati, Ohio - U.S.A.
April 5-6, 1977

# USA·USSR

## SYMPOSIUM ON
## Physical—Mechanical Treatment of Waste Waters

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This symposium was sponsored under the auspices of the Working Group on the Prevention of Water Pollution from Municipal and Industrial Sources.

The thirteen papers that were presented at the symposium (seven US and six USSR) are reprinted in English in this volume in accord with the protocol signed by the delegation leaders on April 16th, 1977.

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## Symposium on Physical-Mechanical Treatment of Wastewaters

United States
Environmental Protection
Agency
Cincinnati, Ohio
April 5th and 6th, 1977

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# Preface

The fourth cooperative USA USSR symposium on the Physical-Mechanical methods of Waste Water Treatment from Municipal and Industrial Sources was held in Cincinnati, Ohio at the U.S. Environmental Protection Agency headquarters on April 5th and 6th, 1977. This symposium was conducted in accord with the fifth session of the Joint USA USSR Commission held in Moscow, USSR from November 15 through 19, 1976.

This symposium was sponsored under the auspices of the Working Group on the Prevention of Water Pollution from Municipal and Industrial Sources. The co-chairmen of the Working Group are H.P. Cahill Jr. of the United States Environmental Protection Agency and S.V. Yakovlev of the Department of Vodgeo in the Soviet Union.

The United States delegation was led by John T. Rhett, Deputy Assistant Administrator for Water Program Operations, U.S. Environmental Protection Agency. The Soviet delegation was led by Yu. N. Andrianov, Director, All-Union Association, Gosstroy.

The thirteen papers that were presented at the symposium (seven US and six USSR) are reprinted in English in this volume in accord with the protocol signed by the delegation leaders on April 16th, 1977.

# Opening Comments

**John T. Rhett**
*Deputy Assistant Administrator for Water Program Operations*
U.S. Environmental Protection Agency

I am extremely honored and pleased to open this fourth symposium in the series undertaken by the US USSR Working Group on the Prevention of Water Pollution from Industrial and Municipal Sources.

This symposium is designed to concentrate on the prevention of water pollution through the application of physical mechanical treatment methods. We have a very comprehensive program on this subject for the next two days. The papers from both the United States and the Soviet participants are outstanding. The results of the symposium will lead to further progress in this very important area of wastewater treatment.

The symposia that our Working Group has undertaken have a planned pattern to cover the most important areas for advancing pollution abatement from municipal and industrial sources. Our first three symposia have already led to useful results from a systematic review of progress to date and potentials for improvement in the future. These first three symposia were:

- Treatment of Wastewater Sludge (USSR — May 12-16, 1975)
- Physical-Chemical Treatment of Wastewater (USA — Nov. 12-14, 1975)
- Intensification of Bio-Chemical Treatment of Wastewaters (USSR — Aug. 22-Sept. 5, 1976)

I look forward to the Physical-Mechanical symposium today to be as distinguished and productive as the prior three symposia. And I know they will be.

I would like to make a few observations from my participation in the symposium and tour of Soviet treatment facilities in August-September 1976.

I was very much impressed by the compatibility and friendliness that has been generated by both the Soviet and American counterparts. Also, I am impressed that each one of these visits extends the circle of acquaintances, professional colleagues and friends. This compatibility has been aided by the people on both sides having common backgrounds and interests in the scientific technical area. I believe that progress in the technical areas could not have been so great without the friendliness and cooperation of our two peoples. I look for this to continue into the future with even greater enthusiasm.

In the United States we have been making progress in water pollution abatement and I am confident we can look forward to continued successes. There are some grimly humorous stories of just how bad things were at one time. On one river, we could not take water samples in metal buckets, because the "water" was so corrosive that it ate the bottoms out of the sampling pails. In another environmental "horror story", Cleveland once considered declaring the Cuyahoga River, which runs through its center, a fire hazard after the River itself repeatedly caught fire. I hope such incidents are, for the most part, in the past.

In case after case, in waters that had been considered biologically dead, or nearly uninhabitable by fish and aquatic plants sensitive to pollution, we are seeing dramatic rejuvenation. Lake Erie is no longer given up for lost. Salmon are returning to the Connecticut River for the first time in generations. The Williamette River, the Detroit River, the Buffalo River, the Houston Ship Channel, are seeing the return of fish and biota that had disappeared for years or decades.

Objectively, the overall net improvement in water quality has been substantial. As measured by three primary indicators of water quality — fecal coliform counts, dissolved oxygen levels, and phosphorus levels — a recent estimate of improvement is on the order of 35 percent of waters tested. This is especially heartening when we consider the growth that has occurred over the past eight or nine years. Our total population served by sewers has grown by 12 percent and wastewater flows have increased by 20 percent.

I am sure I will not minimize the progress we have made to date if I emphasize the complexity and urgency of the problems which still confront us. I would also like to stress the importance of meeting these problems agressively, in the knowledge that we must undertake a long-term commitment if we are to continue our past successes. I know from first-hand experience how much easier it is to muster the initial enthusiasm for an idea than it is to maintain long-term support for even the most worthy or necessary purposes. Yet, it is exactly that long-term commitment which we must accept.

In a sense, dealing with the belching smokestacks and the grossly polluted waters is the easier part of our overall task. These are obvious and dramatic symbols of how the environment can be spoiled. Improvements of such obvious abuses are of course dramatic. Now we must begin to look to the future consequences of our decisions and actions involving the environment. The extent to which we need to make careful plans for the future is sobering. This is why we must face up to the complexities of what we are trying to accomplish, and why I am pleased to be addressing a group that understands the meaning of long-term commitments.

By one estimate, waste treatment plants, in the United States, now generate five million dry tons of sludge each year. By 1990, that figure will double. As a Nation, we now use about 400 billion gallons of water each day, and that figure will double by the end of the century. The demand for drinkable water for municipalities is projected to increase from 30 billion gallons daily to 50 billion gallons. We have no choice — we must ensure that adequate supplies of safe, clean water are available.

We are also fast approaching the situation that in solving one environmental problem, we may create another. What, for instance, do we do with our solid wastes? Even the most carefully designed landfill may release hazardous substances into an aquifer or stream that, in turn, supplies a community with its drinking water. Do we burn our solid wastes, and risk contaminating the air we breathe? Do we dump our sludge at sea, and risk destroying marine ecosystems? How will we deal with the heavy metals and families of organic chemicals which have a notorious tendency to accumulate in the environment? Even such practices as routine chlorination can, in the presence of certain contaminants, create hazardous substances.

Our continued commitment to clean up the environment, the protect the integrity of our natural systems, both in the USSR and the United States, cannot be seen as a luxury, with benefits that are largely aesthetic. We are dealing now with the protection of our present and future health and well-being.

We, in the United States, have just completed our latest municipal needs survey. With the exceptions of control of stormwaters, it indicates that $96 billion is required to abate water pollution to acceptable levels. Stormwater treatment would require an additional $54 billion. You can see that we have a long ways to go.

In dealing with such astronomical figures, even small gains in effectiveness and efficiency in methods of treatment can result in substantial savings in funds that will not have to be expended.

I am sure that the USSR is facing problems of funding pollution abatement that are similar in magnitude to the United States.

I look to our US/USSR Working Group to make substantial gains in so improving treatment methods that benefit each Nation's environment that economy will result. The resulting improvements in treatment methods can also be applied worldwide to the benefit of all peoples.

With this as our objective, I look forward to the results of this symposium.

# Welcome

## Dr. David G. Stephan

It is my great pleasure today, to welcome you to both this joint US/USSR Symposium and to the EPA Environmental Research Center here at Cincinnati, Ohio.

When the US/USSR Working Group on the Prevention of Water Pollution from Municipal and Industrial Sources last met here in November, 1975, this great research facility had not yet been completed. We were able then to show you just the empty shell of our building. Now we have active research and development efforts underway and we will be proud to escort you around to see and understand our activities in research and development.

More important than the fact that this building exists is the place that the Environmental Research Center holds as a key point of international communication in the environmental sciences.

Science knows no national boundaries. Most progress in science is made from the efforts of all scientists, worldwide, cooperatively advancing the frontiers of scientific research to achieve worthwhile results. To achieve these results, however, intercommunication of scientists and technologists must be fostered on a continuing basis. Face-to-face interchange of ideas, as in this symposium, is most helpful in keeping the spirit of cooperation and communication at the highest possible level.

Certainly, in the area of prevention of pollution from municipal and industrial waste waters, this US/USSR Working Group has been a shining example of how to make optimum progress. Concerted effort to interchange both ideas and people during visits to each other countries on a regular basis has been extremely valuable. The Environmental Research Center is honored that it has been an important part of the progress that has been made.

I would like to mention briefly some of the work that we are pursuing that is related to Physical/Mechanical Methods — the theme of this Congress. In the area of industrial processes, we have active work underway, either here or by contract, on:

- joint sludge/refuse processing
- wet oxidation and pyrolysis pilot plant studies
- cost-effective closed water cycle systems in pulp mills
- combined industrial/municipal treatment, with special emphasis on pretreatment standards
- water pollution problems associated with the production of petroleum products
- ground water problems
- reducing pollution from the metal finishing industry
- removal of nitrocellulose from wastewater by ultrafiltration
- recycling treated effluents from paper and board productions, and
- nitrogen removal from meat packing plant effluents

So you can see that we have a well rounded program of research on industrial processes.

But our own efforts are still not enough. The papers that have been prepared by our Soviet colleagues will add substantially to the world's working knowledge of how to achieve more progress in water pollution abatement. And the United States papers are in turn, designed to help add to the knowledge of our Soviet colleagues and to world scientific and technological advancement, in general.

I would like to recommend that this and future symposiums include communication of ideas and methods for toxic pollutant controls. The vast increase in the chemical industry in response to modern social needs has produced the potential for fouling our waterways with dangerous and offensive effluents from industrial processes. Both of our nations face similar problems in ensuring that effluents from modern industrial advances do not harm the very people that it is supposed to benefit.

In recent years, the United States, and I am sure the USSR, have become concerned about the ever-increasing dangers of toxic pollutants. Recently in the United States, for example, carbon tetrachloride and other dangerous chemicals have been released to the nation's waters accidentally. We would hope that significant knowledge on how to prevent releases of toxic chemicals will result from our joint efforts in the Working Group.

In conclusion, I would like to again commend the efforts of this Working Group in advancing the interchange of useful knowledge between the US and the USSR.

I believe that we already see evidence of avoidance of duplication of efforts, while, at the same time, we see the multiplying effect of jointly cooperating to solve common problems.

The key factor is that the welfare of our societies and our citizens, in the US and USSR, will be greatly enhanced by our joint efforts. Let us keep this as our guiding light throughout the proceedings of our two-day symposium.

# Response

## Yu. N. Andrianov

At the present stage of industrial and urban development an increasingly important meaning is assumed by the interrelation of man and nature. The protection of nature from pollution and the rational utilization of natural resources acquire now not only economic but social meaning. This is why in a number of countries this problem is treated on a national level. For successfully dealing with environmental protection the efforts not only of numerous organization, but even of countries, are united and one may say that the problem of environmental protection has crossed the borders of many countries, having united their strengths and means for the preservation of adequate environment for human life.

The protection of water reservoirs for industrial and municipal pollution occupies a significant place in the environmental effort. The complexity of this problem is determined by the continuously growing economic activity of man, by the appearance of complex waste materials, and by an increased demand for quality goods. In its turn, water — an integral part of the majority of industrial processes — demands complex solutions for its regeneration and retention of its natural purity.

In our country the required attention is paid to the environment and to its rational utilization. During recent time a whole series of decisions and laws have been adopted for the protection of the environment, including water resources. Special attention is paid for the protection of purity of rivers, lakes and seas. With this goal in mind the Government has adopted measures for the prevention of pollution of such large water reservoirs as the river Volga, Ural, Lake Baikal, the Caspian and Baltic seas. Efforts in this area have already achieved significant results.

Large projects are scheduled for implementation in our country during the current Five-Year Plan. Capital investments alone are 11 billion rubles. Parallel with this the necessary attention will be given to scientific research efforts for environmental protection, including the protection of water resources.

In this area a significant part of the effort in the solution of water resource protection and the improvement of industrial and municipal water utilization in our country is carried out by the All-Union Association Soyuzvodokanalproyekt, which encompasses the All-Union Scientific-Research Institute Vodgeo. This Association embraces a large number of design and research institutes, their branches and sub-divisions, located in various cities and industrial regions of the country. Such an association of scientists and designers allows the solution of any question related to the organization of water use in newly created industrial enterprises and its improvement in those already in existence.

The Association carries out scientific and design work related to their geographic distribution and their water supply from surface and underground sources, design of sewage systems and the neutralization of industrial and municipal wastes, and the setting up of construction norms and regulations and of national standards.

The largest volume of work of the Association is in the sewage area. Here new methods and facilities are designed for the neutralization of industrial and municipal wastes, zero-discharge and minimum-water-consumption technology implemented, re-circulation and multiple-use of treated effluents systems are set up, including industrial and municipal plants. Wide application is given to the introduction of latest scientific achievements in experimental designing. In cooperation with scientists, the designers of our Association have already built a number of modern facilities and waste-water treatment plants measuring up to highest requirements. For example, the Baikal waste-water treatment plant, designed according to our plans, treats the effluent of the paper-pulp industry to such a high standard that it can be used as drinking water.

A large volume of scientific and design projects in industrial and municipal water use will be carried out by the Association also in the future.

The USSR-US Agreement on cooperation in water pollution prevention from industrial and municipal sources is a significant contribution to environmental protection. In accordance with the outline of this cooperation, Soviet and American specialists are working out methods and facilities for the treatment of effluents in such water intensive areas as paper-pulp, chemical, petro-chemical and oil refining industries and municipal use.

Contemporary research efforts pay greatest attention to the design improvement of settling basins, flotators (flotation systems), aeration tanks, filters and other equipment. Cooperative efforts in this area make it possible — on the basis of existing experience — to design more efficient facilities and to work out new treatment systems.

Regular exchanges of scientific and research information make possible the lowering of costs related to research and the reduction of implementation time for introduction of latest achievements into the practice of waste water treatment.

Symposia, dedicated to practical problems of waste water and sludge treatment, became a fine tradition in our cooperative work. As a rule these symposia are attended by large numbers of specialists of our countries. Their proceedings are published in Russian and English and are disseminated in large number of copies among specialists in our countries.

The present symposium is dedicated to problems related to physical-mechanical methods of waste water treatment. As is known such methods are widely used for the treatment of municipal and industrial waste waters. In spite of the already existing experience in their use, many of these methods require further refinement and also the development of new technological solutions. Exchange of opinions on the efficiency of physical-mechanical methods will be of scientific and practical interest. The work of the symposium will make it possible to determine the main directions of research efforts in the area of physical-mechanical methods for the present and for the future.

In conjunction with the symposium, Soviet and American specialists will discuss future plans and forms of their cooperation.

Joint work of Soviet and US specialists will make it possible to accelerate significantly the technical progress in water resources protection from industrial and municipal pollution and this will be a worthy contribution to the protection of the environment.

# Pyrolysis Applications for Industrial and Municipal Treatment

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## Introduction

As suggested by the title, this presentation focuses on the applications and energy recovery aspects of pyrolysis for municipal and industrial treatment.

Pyrolysis is the decomposition of organic materials in an oxygen starved atmosphere. In the absence of oxygen, organic material is driven from the solids in the form of combustible pyrolysis gas. Complete oxygen starvation would necessitate firing fuel for heat, but with the multiple hearth furnace (MHF) partial combustion of the feed supplies the heat for the pyrolysis reaction. Combustion is minimized by supplying only air to obtain optimal processing temperatures.

For autothermic pyrolysis, feed materials that yield a gas combustion temperature in excess of 649°C (1200° F) are necessary. This corresponds to a feed energy level of above 3500 BTU's per pound of feed water. With feed levels having in excess of 6000 BTU's per pound of water, pyrolysis becomes a virtual necessity because in an incineration mode elevated furnace temperatures would result in creating the likelihood of material fusion.

Pyrolysis has been utilized for processes having high energy feed materials such as carbon activation, carbon reactivation, char production, and other carbonization devolatilization processes.

In the pyrolysis mode, a multiple hearth furnace can handle materials containing more than 30,000 BTU's per pound (.45 kg) of feed water and still maintain mid-zone temperatures below 833°C (1500°F), and outlet temperatures less than 649°C (1200°F). The temperature in the external combustion or afterburner chamber could exceed 1649°C (3000°F). The significance of elevated afterburner temperatures is the increasing driving force for steam production in a heat recovery boiler.

## Multiple Hearth Furnace Description

Shown in Figure 2 is a multiple hearth furnace cross-section showing the various zones of operation used for the pyrolysis method of thermal processing. The size and number of hearths are determined by evaluating the process time and feed material characteristics. A minimum six-hearth furnace is recommended as the best configuration for most applications.

Furnace specifications are modified for optimal handling of the particular feed material. Materials requiring large combustion volumes and low solids processing residence time are designed with an enlarged external afterburner and small hearth areas. The one-hearth furnace design with external afterburner represents the extreme situation of large combustion volume with little or non-existent solids handling processing area.

The furnace is usually loaded at the top. Rotating arms on a vertically positioned shaft spiral.the material in a counterclockwise direction across the hearths. The hearths have alternating center and peripheral drop holes such that material falling through a peripheral drop hole is pushed toward the center of the next hearth. On the hearth having a central hole, material is spiraled around toward the outside, and so on (see Figure 2).

The arms all move in the same direction and alternate inward and outward movement of material is obtained via the angling of the plows (rabble teeth). This design provides substantial opportunity for retention time and zone control. Retention time is controlled by the setting of the variable speed shaft drive, which sets the rotational speed of the arms and the orientation of the rabble teeth. Each hearth can be controlled for temperature and atmosphere (degree of oxidation (or reduction).

The hearths are refractory, the shaft is refractory insulated cast iron, and the arms and teeth are usually cast alloys. The orientation of rabble teeth determines bed depth, total surface area and retention time. The live bed depth, the area between the bottom of the rabble teeth upward, is adjusted for the particular process.

**Process Advantages**

Essentially, there are two steps in the pyrolysis process: the first is the conversion of organics to gases; and the second is the combustion of the pyrolysis gas to recover heat energy.

The pyrolysis operating mode offers a combination of advantages and benefits compared to incineration, as follows:

**1.** Improved process control of temperature, and minimization of excess air.
**2.** For material with high energy content (above 6000 BTU pound (.45 kg) of feed water) low temperature (1500°F) pyrolysis prevents material fusion or clinker formation;
**3.** Pyrolysis minimizes dependence on energy sources while offering energy recovery to offset the energy demand of treatment plants;
**4.** Reduced furnace size per quantity of dry solids;
**5.** Reduction in particulate loading prior to scrubbing;
**6.** It offers potential revenue from steam or power generation, and
**7.** It affords opportunity to reclaim or recycle waste materials and in the process eliminates the environmental problems associated with waste in the processing of raw materials.

**Industrial Applications**

In the petroleum industry pyrolysis has earned a proven record for effectively handling high energy sludges. Processing oil filtration sludges having minimal water and filter earths is easily controlled by the pyrolysis operating mode, which serves to reduce hearth temperatures, prevents fusion, and helps maintain longer furnace life.

A major U.S. petrochemical plant recently selected multiple hearth furnaces over fluidized bed furnaces to pyrolyze wasten aerobic sludge and still bottoms. The high concentration of chloride salts in the sludge and the resultant fusion effect of such salts at high temperatures requires the specification of pyrolysis for disposal of the sludges. The organics from the high energy sludge, 8000-9000 BTU/pound (.45 kg) water, will volatilize at comparative low temperatures approximately 538°C (1000°F). The volatile gases will exit the furnace at a temperature of 482°C (900°F) and be combusted in an external afterburner at 802°C (1475°F).

The automotive industry has successfully used pyrolysis to reclaim cast-iron borings from engine blocks. The process reclaims cast-iron by volatilizing cutting oils to form gases. Combustion of a portion of the gases provides the heat energy to evaporate the moisture and heat the cast-iron chips prior to briquetting at 538°C (1000°F). In this application, the advantage of pyrolysis is to prevent fusion problems, reduce furnace wear and improve control of process conditions.

Pyrolysis in a MHF has been shown as an ideal method for reclaiming waste materials via charcoal production. In this process organic materials are re-volatilized at 538°C (1000°F) to 863°C (1600°F). The introduction of air is s controlled to maximize the formation of fixed carbon,or char.

The C.B. Hobbs Corporation uses the pyrolysis process to produce charcoal from 50,000 tons (22,727,000 kg) of nutshell and fruit pit wastes each year. This Elk Grove, California, corporation uses the waste to produce a salable product — charcoal. This process also solves the waste disposal problems of growers, canners and processors. The 50,000 tons (22,727,000 kg) of waste are used to produce 35,000 tons (16,000,000 kg) of high quality charcoal annually.[1],[2] The typical mixture includes peach, apricot and olive pits, plus walnut and almond shells. The heat for drying the wet wood or other waste materials can be supplied by the hot gases from the combustion stack, which saves energy.

## Municipal Treatment

As demonstrated by a wealth of experience from municipal sewage treatment plants, the multiple hearth furnace is one of the more environmentally sound and economically justifiable methods of handling the escalating volumes of sewage sludge. The need for improved sewage sludge processing is increased because of advanced water treatment methods, which generates increased sludge volumes. Jones et al.[3] estimates that the total sludge solids (dry basis) requiring disposal could exceed 23,000 tons per day (10,454,000 kg) by 1985 in the United States. Presently there are over 300 multiple hearth sludge furnaces in existence. Furnaces process between 25% and 30% of all sludge in the United States, with the multiple hearth configuration representing about 75% of these thermal processing units.[3]

Recognizing the environmental problems associated with the disposal of large quantities of sewage sludge, the New York New Jersey Interstate Sanitation Commission in a joint effort with the United States Environmental Protection Agency has evaluated the most cost effective and environmentally sound alternative to ocean dumping in the New York-North New Jersey Metropolitan area. This technical report, prepared by Camp, Dresser & McKee, found pyrolysis to be the best alternative to ocean disposal.

### Energy Recovery

The recent substantial increases in the costs of energy and fuel consumption are a cause for major concern in the evaluation of sewage disposal processes. As stated by Shannon et al.[4] of Environment Canada, "It is a popular misconception that energy cost increases will severely affect the economic feasibility of sludge incineration. In fact, recent developments in sludge dewatering, heat recovery and reuse will actually make sludge incineration energy self-sufficient."

Pyrolysis represents an advanced thermal design that progresses beyond the elimination of fuel requirements to recycle the sludge's inherent fuel values into power.

The Cowlitz County Municipal Wastewater Incinerator plant, which started up June 1, 1976, for example, has a full scale MHF unit that has been run in a partial pyrolysis operating mode. The furnace is a 12'9" (3.9 meters) OD by 7 hearth model which is designed to handle 748 kg/hr (1645 lb/hr) of dry solids containing between 30% and 40% moisture.

Heat treatment or thermal conditioning of the sludge allows it to be readily dewatered to about 40% solids, which is sufficiently dry to create a net exothermic heat balance and could produce steam required for the heat treatment operations, plus additional steam for the plant.

In their search for better operating techniques, the Cowlitz County plant management has achieved the proper parameters to operate the multiple hearth furnace without auxiliary fuel. At this installation autothermic (without auxiliary fuel) processing occurs when the sludge is dewatered to approximately 40% dry solids. Then the furnace temperature profile is maintained by the controlled and selective addition of air to limit rather than quench the temperature rise at each hearth. This ingenious operating technique maximizes the operating efficiency and fuel economy of the plant while minimizing the power consumption of the off-gas system by reducing the quantity of excess air.

The operator requirements are also minimized due to the operational stability; such services are limited primarily to periodic checks and minor corrective adjustments.

The technique of temperature control through air limitation pyrolysis is responsible for the operational benefits mentioned above while simultaneously meeting the latest EPA state of the art requirements of particulate emissions and odor. While it is important to emphasize that the furnace operates without any auxiliary fuel, a further improvement in this system will be the addition of a waste heat recovery boiler between the furnace outlet and the scrubber system. The heat recovered from the furnace off gases can then be used to produce steam to satisfy or supplement the energy requirements of the treatment plant.

Another type of pyrolysis treatment for sewage sludge has been performed on a demonstration basis. Full scale tests completed July 30th at the Concord, California, Wastewater Treatment Plant have shown that pyrolysis of municipal solid waste and sewage sludge can be used as a source of energy for wastewater treatment plants.

The Concord project started in November, 1974, when the concept was proven at Envirotech's Brisbane, California, test facility. Results were so promising that the EPA gave grant authorization for full scale modifications and tests at an available furnace at Concord, California. This testing started in May, 1976, at rates of 2-4 tons (1-1800 kg) an hour, and was carried out by Envirotech Corporation under a contract from Brown and Caldwell, the consulting engineers on the project. It involved combusting and pyrolyzing mixtures of refuse and sludge in a multiple hearth furnace. Sponsors of the project were the Central Contra Costa Sanitary District, the State of California, and the Environmental Protection Agency. A complete report on the project was presented in December.[5]

The study was aimed specifically at finding ways to cut the cost of tertiary wastewater treatment and solids disposal at the nearby Central Contra Costa Sanitary District Water Reclamation Plant. The 30 mgd (113,550 $m^3$/day) regional facility, now under construction, will recycle domestic sewage into high quality water for industrial process and cooling use by mid-1977.

To offset the potentially high energy bills in operating the new plant which could be incurred as a result of unprecedented price increases over the past three years, studies were conducted on how to utilize as an energy source the 1000 tons (454,000 kg) a day of municipal solid waste currently generated in the district and disposed in a landfill. In addition to eliminating auxiliary fuel, producing energy, and disposing of wastes, pyrolysis will extend the life of the landfill. Existing multiple hearth incinerators can be converted to pyrolysis furnaces.

The recommended process calls for two-stage shredding, followed by metal reclamation and air classification of the solid waste to produce a refuse-derived fuel (RDF). The RDF is fed to the furnace along with sewage sludge and pyrolyzed to produce a combustible gas. No auxiliary fuel is required for the process.

Results to date indicate that the fuel gas has sufficiently high heat content to provide over 90% of the plant's energy requirements. Plans are for the gas to be used to fuel a lime recalcining furnace at the district's water reclamation plant. Other uses will be to produce steam for steam driven mechanical drives, for plant heating and cooling systems, and for electrical power generation. Indicative of the potential energy available from this process, afterburner temperatures in excess of 1316°C (2400°F) were recorded at the Concord site.

## Energy Recovery Economics

As previously mentioned, with proper dewatering techniques, pyrolysis of sewage sludge should not require supplementary fuel and could be operated to recover energy. As the price of energy continues to escalate, the economic benefit of energy recovery will become more significant.

Using preliminary data for equipment systems and disregarding building and other peripheral plant expenditures, it appears that systems similar to the Contra Costa example (using a mix of sewage sludge and refuse) can recover enough energy to pay back the capital, fuel, power, labor and chemical costs associated with sludge handling within a short time period. The degree of energy recovery is dependent on the moisture content of the sludge and refuse and also will vary according to the content ratio of refuse to sludge.

The economic advantages of pyrolysis systems vary according to plant design and feed materials. To illustrate the benefits that are available from the use of pyrolysis, a comparison was done of the costs of three types of solids handling systems for a 50 MGD (190,000 $m^3$/day) sewage treatment plant treating both primary and secondary sludges.[6] The solids processing systems that will be discussed are as follows:

**Case 1:** a MHF that processes sludge and scum in an incineration mode;
**Case 2:** a MHF that processes sludge and scum in a pyrolysis mode;
**Case 3:** a MHF that processes sludge, scum and refuse derived fuel (RDF) also in a pyrolysis mode.

The values assumed for the costs and the variables associated with power, fuel, and chemicals that were used to compare the three options are listed in Figure 3. The solids handling flowsheets and economic data associated with these three options are given in Figures 4 to 6. Both pyrolysis flowsheets include chemical conditioning, filter pressing and energy recovery equipment, while the incineration flowsheet has no energy recovery equipment and uses centrifugation instead of a filter press. It should be stated that building, foundation and other peripheral expenses not directly related to the handling equipment were omitted from the calculations.

A perusal of cases 1 through 3 contrasts the economic differences between a conventional incineration system and that of pyrolysis. This comparison demonstrates how a pyrolysis feed mixture of RDF and sludge can actually generate a positive revenue (Figure 6). The energy recovery savings in Case 2 could significantly reduce the cost (per ton of dry solids) of sludge handling compared to Case 1 (Figure 4) which has no energy recovery benefits. Case 2 is able to recover enough energy to supply 55% of the entire annual energy requirement for the sewage treatment plant. These savings are roughly equivalent to a third of the annualized costs for the solids handling process.

The economic advantages of pyrolysis are further accentuated when a mixture of sludge and RDF are processed. In such situations pyrolysis systems have the advantage over conventional thermal systems by producing revenue. As more RDF is added to the sludge feed the dry solids content of the feed is elevated, which serves to increase the amount of recoverable steam energy. Additionally, the problem of solid waste (RDF) disposal is also achieved. For example, in Case 3 where 12 parts of RDF are added per equivalent of sludge, enough energy can be recovered to offset the entire annualized costs of the solids dewatering and pyrolysis processes with enough energy left over to equal a revenue of $1.1 million (834,000 rubles). Hence, pyrolysis can be used to dispose of large quantities of RDF (solid waste) and sludge, and can recover energy that could be useful as a revenue source to offset the costs of sewage treatment. The prospect of revenue production is an opportunity that most, if not all, other types of solids processing systems cannot offer.

## Summary

In conclusion, it should be reiterated that pyrolysis in a multiple hearth furnace has a number of advantages over conventional incineration, which are as follows:

1. Improves process control;
2. Prevents clinker formation (material fusion);
3. Offers economical energy recovery;
4. Increases furnace capacity;
5. Offers potential revenue from steam or power;

6. Reduces particulate loading prior to scrubbing;
7. Offers a permanent solution to solids (RDF) disposal, and
8. Has numerous industrial applications.

Pyrolysis in a MHF has in common with MHF incineration a number of advantages compared to other solids handling systems, some of which are:
1. Meets U.S. EPA emission regulations;
2. Offers permanent solution to sludge disposal;
3. Has been proven technologically on a full scale, and
4. Avoids bacterial, viral and organic contamination of ground water by thermal destruction.

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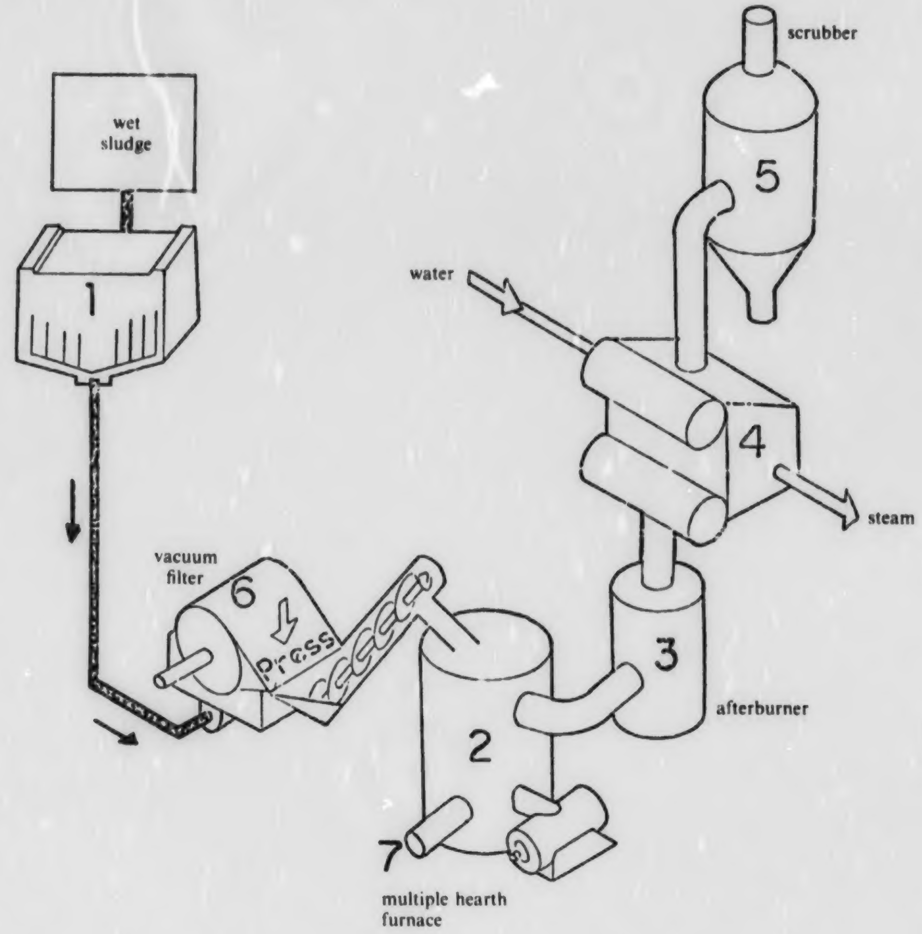

scrubber
wet sludge
5
1
water
4
steam
vacuum filter
6
Press
3
afterburner
2
7
multiple hearth furnace

**Figure 1.**

**Sludge Pyrolysis and Heat Recovery**

1. Thickner
2. Pyrolyzer
3. 1500°F Combustion
4. Waste heat recovery boiler (turbine generator optional)
5. Cleansed air
6. High solids filter
7. Purified ash with phosphate

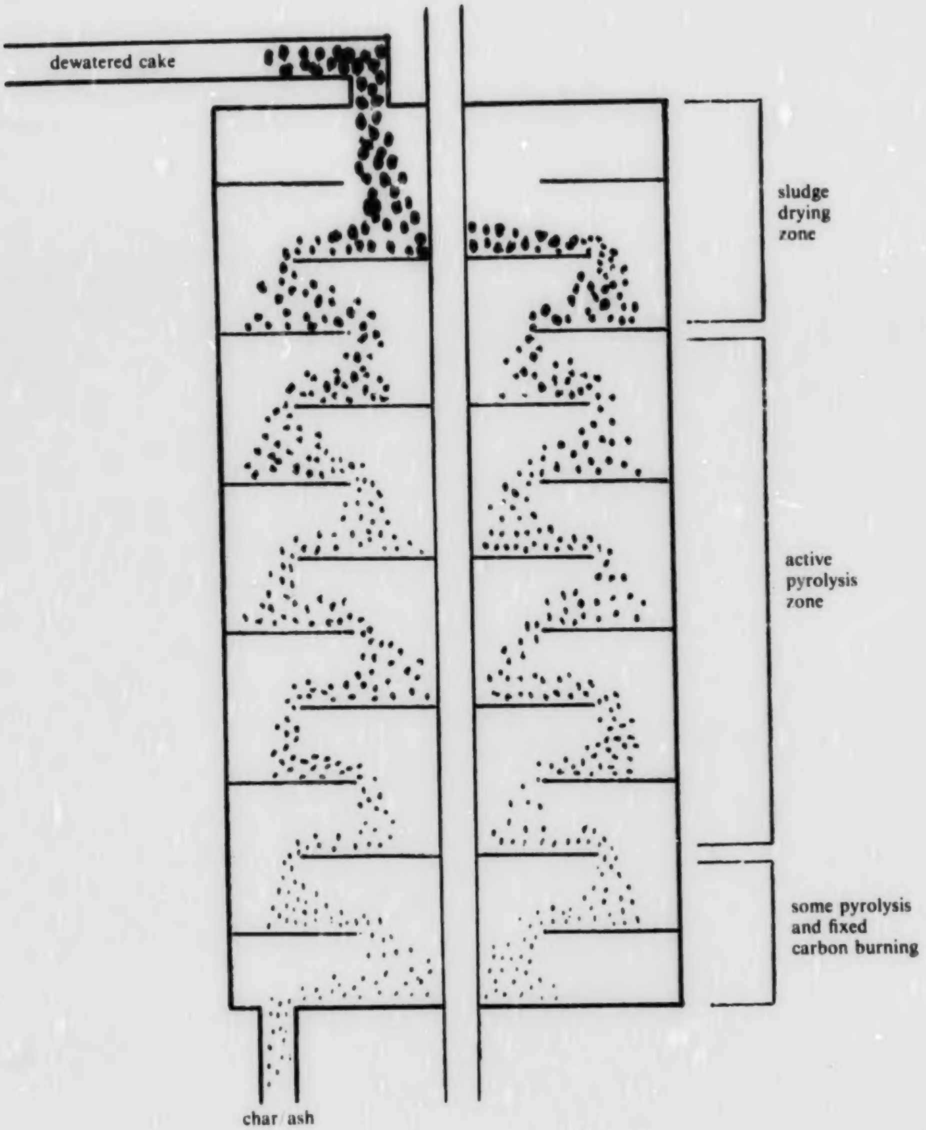

dewatered cake
sludge drying zone
active pyrolysis zone
some pyrolysis and fixed carbon burning
char/ash

Figure 2.
**Pyrolysis**

## Basis for Economic Calculations

## 50 MGD (190,000M$^3$/day) — primary + secondard

| | | |
|---|---|---|
| **Power** | $0.03/KW-HR | (2 Kopecks/KW-HR) |
| **Chemicals** | $75/Ton | (25 R/1,000 KG) |
| **Fuel Oil** | $0.40/Gallon | (1.2 R/Liter) |
| **RDF** | $10/Ton | (3.4 R/1,000 KG) |

| | |
|---|---|
| **Non heat treat sludge** | 10,000 BTU/# Volatiles |
| **Heat treat sludge** | 12,000 BTU/# Volatiles |
| **Scum** | 16,000 BTU/# Volatiles |
| **RDF** | 8,500 BTU/# Combustibles |
| **Continuous operation** | 8,760 HRS/Years |

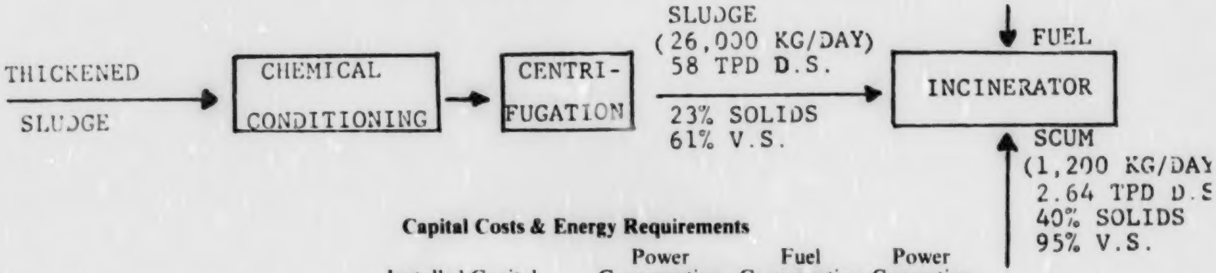
Capital investment amortized over 20 years

Municipal bonding rate of 6%

No water, building or labor cost included

Figure 3.

## Case 1: Solids Disposal Costs For a 50 MGD Plant


THICKENED SLUDGE
CHEMICAL CONDITIONING
CENTRI-FUGATION
SLUDGE
(26,000 KG/DAY)
58 TPD D.S.
23% SOLIDS
61% V.S.
FUEL
INCINERATOR
SCUM
(1,200 KG/DAY
2.64 TPD D.S
40% SOLIDS
95% V.S.

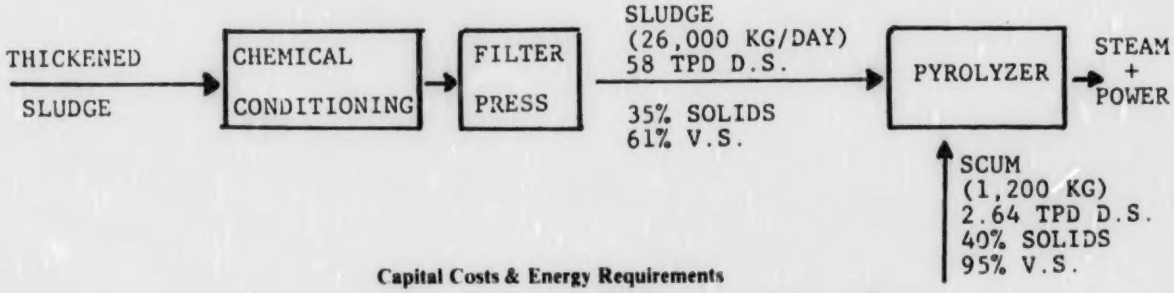
**Capital Costs & Energy Requirements**

| | Installed Capital Equipment Cost | | Power Consumption (KW.) | Fuel Consumption (GPD) | Power Generation (KW) |
|---|---|---|---|---|---|
| **Centrifugation** | $ 250,000 | ( 190,000 R) | 154 | | |
| **Incinerator** | $2,268,000 | (1,718,000 R) | 146 | 796 | |
| **Total** | $2,518,000 | (1,908,000 R) | 300 | 796 | |

| **Annualized Costs** | **(1,000's of $)** | **(1,000 Rubles)** |
|---|---|---|
| **Capital** | 220 | 167 |
| **Power consumption** | 79 | 60 |
| **Chemicals** | 279 | 211 |
| **Fuel** | 116 | 88 |
| **Total cost** | 694 | 526 |
| **Power revenues** | 0 | 0 |
| **Cost per ton D.S. ($/Ton)** | 37.4 | 28 |

Figure 4.

## Case 2: Solids Disposal Costs For a 50 MGD Plant


THICKENED
SLUDGE
CHEMICAL
CONDITIONING
FILTER
PRESS
SLUDGE
(26,000 KG/DAY)
58 TPD D.S.
35% SOLIDS
61% V.S.
PYROLYZER
STEAM
+
POWER
SCUM
(1,200 KG)
2.64 TPD D.S.
40% SOLIDS
95% V.S.

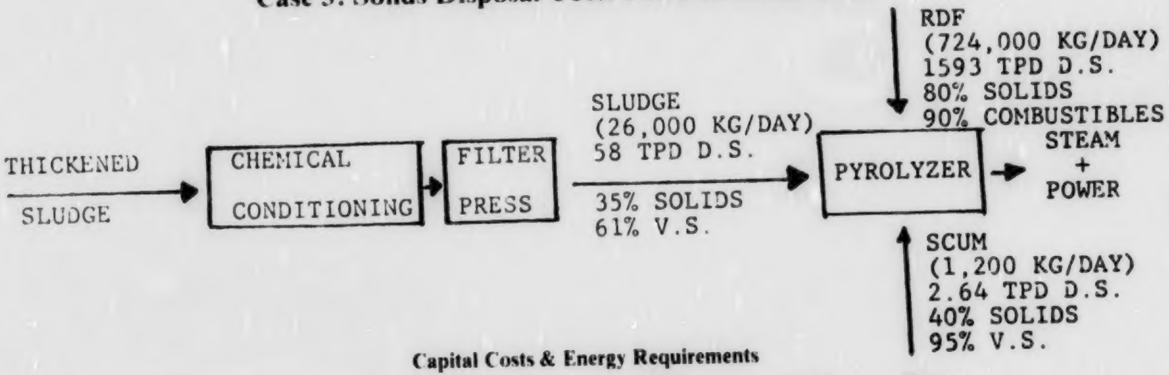
**Capital Costs & Energy Requirements**

| | Installed Capital Equipment Cost | Power Consumption (KW.) | Fuel Consumption (GPD) | Power Generation (KW) |
|---|---|---|---|---|
| **Filter Press** | $ 603,000 ( 457,000 R) | 11 | | |
| **Pyrolyzer** | $1,950,000 (1,340,000 R) | 135 | | 757 |
| **Total** | $2,553,000 (1,797,000 R) | 146 | | 757 |

| **Annualized Costs** | **(1,000's of $)** | **(1,000 Rubles)** |
|---|---|---|
| **Capital** | 266 | 201 |
| **Power consumption** | 38 | 29 |
| **Chemicals** | 279 | 211 |
| **Total cost** | 583 | 441 |
| **Power revenues** | 199 | 151 |
| **Net cost** | 384 | 291 |
| **Cost per ton D.S. ($/Ton)** | 20.7 | 16 |

**Figure 5**

## Case 3: Solids Disposal Costs For a 50 MGD Plant


RDF
(724,000 KG/DAY)
1593 TPD D.S.
80% SOLIDS
90% COMBUSTIBLES
THICKENED SLUDGE
CHEMICAL CONDITIONING
FILTER PRESS
SLUDGE
(26,000 KG/DAY)
58 TPD D.S.
35% SOLIDS
61% V.S.
PYROLYZER
STEAM + POWER
SCUM
(1,200 KG/DAY)
2.64 TPD D.S.
40% SOLIDS
95% V.S.

**Capital Costs & Energy Requirements**

| | Installed Capital Equipment Cost | Power Consumption (KW.) | Fuel Consumption (GPD) | Power Generation (KW) |
|---|---|---|---|---|
| **Filter Press** | $ 603,000 ( 457,000 R) | 11 | | |
| **Pyrolyzer** | $19,000,000 (14,400,000 R) | 3,014 | | 42,460 |
| **Total** | $19,603,000 (14,857,000 R) | 3,025 | | 42,460 |

| **Annualized Costs** | **(1,000's of $)** | **(1,000 Rubles)** |
|---|---|---|
| **Capital** | 1,719 | 1,302 |
| **Power consumption** | 795 | 602 |
| **Chemicals** | 279 | 211 |
| **R.D.F.** | 7,268 | 5,506 |
| **Total cost** | 10,061 | 7,621 |
| **Power revenues** | 11,158 | 8,453 |
| **Net revenue** | 1,097 | 831 |
| **Revenue per ton D.S. ($/Ton)** | 59 | 45 |

**Figure 6.**

# Waste Water Treatment by Physical and Mechanical Methods.

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Industrial development and municipal improvements inevitably involve formation of wastes , part of which is discharged into water reservoirs. the same time a successful realization of plans of national economy is determined by various factors including the quality of water sources.

In this connection the modern human activities and environmental control are closely interrelated.

Considering the importance of this problem the majority of countries have taken a number of measures maintaining the safety and cleanness of natural water sources. Considerable allocations have been made at present to solve this problem.

The difficulty of rendering safe the contaminants consists in the composition of industrial and domestic effluents and their big amount. However, the ever growing requirements for the quality of water treatment are not always met by existing treatment plants. Therefore there is a necessity of developing existing methods and elaborating new ones with the purpose of water sources protection. In spite of sufficiently high level of rendering industrial and domestic effluents much attention is paid to these problems in the USSR and USA. In this respect uniting efforts and means of both countries to solve the problems of water medium protection will be efficient and mutually profitable from an economical point of view.

The most efficient measures taken at present to protect water reservoirs against contamination with industrial and domestic wastes are waste water treatment, use of closed water supply systems, working out of technological processes which are not associated with generation of waste water, repeated use of treated industrial and municipal effluents in technological processes of enterprises etc.

Mechanical, physicomechanical, physicochemical and biochemical methods are used to treat industrial and municipal effluents. Depending on the composition of effluents, local conditions and other aspects use is made at enterprises of systems that include a combination of various methods and installations.

The methods and installations of physicomechanical treatment are widely used in municipal services and industry. They allow it to separate from waste water solid mechanical impurities of mineral and organic character as well as a number of dissolved matter (for instance, surface active matter). Depending on quality and quantity of waste water it is treated by various modifications of sand traps settling tanks, hydrocyclones, centrifuges, flotators, filters etc.

To intensify the process of treatment, use is now made of some new methods such as water treatment with magnetic or electric field, vibration, ultrasound, various reagents. In a number of cases these measures bring about structural changes or designing special treatment apparata.

The use of above mentioned installations in each particular case is determined by a number of factors and principally by water properties, character of impurities it includes and by required degree of treatment.

One of the widely used methods of water treatment is sedimentation. This method is used due to simplicity of installations, low operational costs. These installations permit removal of up to 40-60% of mechanical impurities from water, 90% and over oil products and to reduce BOD and COD values.

These installations are designed on the basis of kinetic curves of settling (Fig. 1) determined by experiments. These curves characterize sedimentation properties of suspended matter in waste water.

To model the sedimentation process a number of relationships have been suggested. Let us take one suggested by the institute under the academy of municipal services:

$$\frac{T}{t} = \frac{H}{h}^{n} \qquad (1).$$

where h, H — sedimentation height accordingly in the model and in a real installation;
t, T — corresponding sedimentation period in the model and in a real installation;
n — agglomeration coefficient of settling particles.

As proved by investigations, the "n" value depends on many parameters of sedimentation process including the origin of suspended matter and may vary within a considerable range from 0.2 to 1.

Determination of "n" value (for recalculation of experimental characteristics for actual installation) is done on the basis of two sedimentation curves obtained in a laboratory for different depths ($n_1$ and $n_2$) of sedimentation (floating) and assigned treatment efficiency (Fig. 1)

$$n = \frac{\lg t^2 - \lg t^1}{\lg h^2 - \lg h^1} \qquad (2)$$

As it has been already noted use is made of various types of settling tanks. They can be rectangular, round, cylindrical etc. Depending on working flow direction settling tanks are subdivided into horizontal, radial and vertical (Figs. 2, 3, 4).

The main disadvantage that reduces the efficiency of employed settling tanks is a considerable flow movement due to imperfection of water collecting and water distributing equipment as well as due to the effect of convective flows as a result of irregular temperatures in the installation. That is why the volume of the settling tank is not entirely used.

Investigations show that the volume utilization factor (efficiency) of settling tanks is, as a rule 50-60%, of radial 50-60%, of vertical 40-50%.

The required period of working flow staying in the installation to provide necessary degree of treatment is determined on the base of sedimentation curves according to the formula:

$$T = t\left(\frac{H}{h}\right)^{n} \quad ; \quad \epsilon = \text{const} \qquad (3)$$

When specifying dimensions of a settling tank in accordance with the amount of waste water one should consider the volume utilization coefficient.

Due to a low efficiency of settling tanks they require considerable installation areas which is sometimes the reason for their limited use.

One of the ways to increase the efficiency of settling tanks is improving water distributing and water collecting equipment. An example of such improvement is attachment of the perforated partition installed at the inlet of a settling tank and increasing the length of spillway edge.

The total area of holes in the partition is taken 6-8% of the settling tank section. To increase volume utilization coefficient of vertical settling tank provision is made for arranging distribution grates and changing the inlet system (Fig. 5).

It has been determined that in installations with small settling depth the influence of density and convective flows on the velocity of working flow of liquid is miserable and its distribution provided at the inlet remains practically unchanged along the entire length of the settling tank.

This principle is used in structures of shelf-type and tubular settling tanks.

A variety of thin-layer settling tanks is known at present. In accordance with the scheme of water flow and sediment movement, all thin-layer settling tanks can be subdivided into three groups.

The first group includes settling tanks which operate according to cross scheme when the sediment creeps across the flow movement; the second group counter-flow scheme, when the sediment creeps against the flow movement and the third group settling tanks operating according to straight-flow scheme when the direction of sediment movement and that of water flow coincide.

Hydraulic investigations of thin-layer settling tanks that operate according to cross scheme and is provided distribution devices have been carried out by VODGEO. The investigations have shown that maximum efficiency of volume utilization up to 80-90% is achieved in case of using proportional water distribution devices designed by VODGEO (Fig. 7). Testing as thin-layer settling tank in real conditions at one of the oil-refining plants has proved the high efficiency of this installation for oil removal. Under a hydraulic load which is five times greater, this installation provides the same efficiency as an oil catcher which is 36 m long, 6 m high and 2 m deep.

Investigations which are being carried out at present on thin-layer settling tanks aim at widening the field of their use.

The process of separating mechanical impurities from water is intensified in the field of centrifugal forces. The degree of intensification is characterized by the separation factor.

$$Fr = \frac{V^{2}}{g.R}$$

where V — linear speed of rotation, m/sec.,
q — acceleration of gravity force, m/sec$^2$,
R — radius of rotation, m.

To clean waste water from roughly dispersed impurities use is made of pressure hydrocyclones (Fig. 8) where centrifugal field is maintained owing to tangential inlet of feed water.

The industry of the USSR produces pressure hydrocyclones from 9 to 500 mm dia. Greater treatment efficiency is achieved in hydrocyclones of small diameters. These cyclones are assembled into blocks. Hydrodynamic investigations on pressure hydrocyclones show that their separation factor can reach $Fr = 5000$ which indicated a greater separating ability of these apparata. However due to a short period of flow staying in hydrocyclone and due to turbulence caused by zones of flow circulation, the provided treatment efficiency is much less than theoretical one. Another disadvantage of pressure hydrocyclones is the wearing of walls in case of treating waste water contaminated with abrasive suspended matter.

This feature confines the field of using three apparata.

Pressure hydrocyclones are used as a rule, for local treatment of small quantities of industrial waste water contaminated by roughly dispersed impurities.

They are used in chemical industry, building materials industry, at concentration plants, for treatment of mine waste water etc.

Of great use can be exposed hydrocyclones which according to the character of separation process hold intermediate position between settling tanks and hydrocyclones.

A relatively small speed of liquid entering this apparata results in a small hydraulic resistance which does not exceed 0.5 m w.c and in much greater efficiency as compared to that of pressure hydrocyclones.

Rotation movement in exposed hydrocyclone enables agglomeration of suspended matter which increases the efficiency of the sedimentation process. Therefore hydraulic unit loads ($m^3/m^2hr$) on these installations are greater than those on settling tanks.

Several structures of exposed hydrocyclone have been designed by VODGEO research institute. Of great interest is the hydrocyclone with internal cylinder and tapered membrane located in the upper part (Fig. 9) as well as multistage hydrocyclone.

In the first structure water is fed to the space confined by the internal cylinder. This cylinder enables it to create a closed water flow which delivers suspended matter separated from the rising flow to the tapered part. The membrane located in the upper part of the apparata as well as the end wall at the end of the horizontal settling tank prevents suspended matter which is moving together with a rising flow from discharge.

Industrial tests of this structure on waste water from rolling mills have shown that the same treatment efficiency can be achieved under the load which is 2.5 times greater than that on settling installations.

The principle of thin-layer sedimentation realized owing to subdivision of structure volume into separate tiers by means of tapered membranes is used in multistage hydrocyclone.

The rotation movement of working flow achieved by tangencial inlet of initial water through three vertical slots which are common for all tiers contributes to agglomeration of suspended matter and to better volume utilization of tiers (70%).

Testing multistage hydrocyclone for treatment of waste water from rolling mills has shown that the required treatment efficiency is obtained with hydraulic loads several times greater than those on ordinary settling tanks.

Unlike the pressure hydrocyclones the exposed ones can be used for separation of coagulated suspended matter. Rotation movement intensifies coagulation and flocculation processes.

Of interest are also other apparata of physicomechanical treatment where contaminants are separated under the action of centrifugal forces. These are bowl centrifuges.

The main advantage of bowl centrifuges as compared to settling installations is the compactness of installations owing to great hydraulic loads with higher clarification efficiency as well as the possibility of simultaneous sediment treatment.

This advantage plays an important part when chosing the proper method of waste water treatment for enterprises with limited areas.

Very advantageous types of centrifuges for industrial sewage treatment are pendulum (basket-type) centrifuges of interrupted action and scroll centrifuges of continuous action.

Pendulum centrifuges (Fig. 10) afford to achieve complete clarification of waste water and sufficient dehydration of sediment. However, the intervals in operation due to the necessity of removing the sediment make the field of its use limited. Investigation carried out by VODGEO have shown that treatment of waste water with contaminant concentration over 3 g/l is not reasonable.

Particularly efficient is the use of pendulum centrifuges for local treatment of waste water generated at enterprises with interrupted technological process.

Scroll centrifuges (Fig. 2) are much more efficient as compared to pendulum ones. However, as shown by investigations, the efficiency of waste water clarification in these apparata depends on the properties of waste water and generated sediment and in some cases is lower than in pendulum centrifuges.

Investigations carried out by VODGEO have shown it reasonable to use low-speed centrifuges with a separation factor up to $F_r = 800$. In this case it is possible to design high capacity centrifuges. That is why further investigations carried out at present are aimed at studying their structural pecularities with the purpose of designing special high efficient installations for waste water clarification.

One of the widely spread methods of waste water treatment and sediment compaction is flotation. This method allows removal of mechanical impurities from waste water as well as fine-dispersed matter, dissolved and surface active matter and in some cases even ions and molecules.

This method can be successfully used to remove substances with water-repellent properties from waste water.

The possibility of getting air or gas bubbles having the same sizes as those of removed particles ensures high efficiency of treatment and affords to get the required water quality since flotation plants can be automatized.

Flotation is used in home practice for industrial waste water treatment in such branches of industry as chemical, oil-producing, oil-processing, metallurgical, machine building, food, cellulose-paper, textile etc. as well as for treatment of municipal effluents.

The capacity of flotation plants varies within a considerable range and reaches the load of 1500 $m^3$/hr and over per frother cell. The diameter of such installation can be up to 30 m.

In most cases it is possible using flotation to remove the basic amount of suspended matter, surface active matter, oil products, fats, oils etc. The efficiency of contaminant removal reaches 60-80% and in case of reagents use — up to 90-95% and over.

Flotation is also used of late for final purification of biologically treated waste water.

In this case suspended matter and sometimes hardly oxidized matter which have passed aeration tanks are removed from water. In case of pressure flotation, for instance, a considerable amount of oxygen is dissolved. Oxygen content in treated water exceeds by 30-50% its concentration.

Various schemes of flotation plants and frother cell designs as well as combined installations are used in practice: hydrocyclones-flotators, flotators-settlers, filters-flotators, flotators combined with reagent mixing and flocculation chambers etc.

Available experience and investigations of flotation show that this method of treatment-compression (pressure) flotation, impeller, frothy, electroflotation etc. will be still wider used for waste water purification and sediment treatment.

Installations with filtering charge are widely used in systems of physico-mechanical treatment. As the working medium, use is made of various natural materials such as for instance adequate fractions of sand, hard coal, rock as well as specially prepared charges of slag, ceramics, polymer materials. Metal nets and various filtering arrangements are used for this purpose. Working medium of the filter can be arranged from one material (two-three layer) which in turn determines technical and economic characteristics of installation operation.

In most of the cases filters are used for considerable water cleaning from suspended matter and are most frequently used in treatment systems of industrial plants and municipal services after aeration facilities. In home practice, for instance sand filters are used at treatment plants of oil-refineries and some chemical industries before aeration tanks. The capacity of filters varies within a considerable range and depends on a number of conditions. The rate of filtration for single-layer and double-layer sand filters used in home practice can be as a rule, within 3-20 m/hr.

For instance the rate of filter used for final purification of biologically treated waste water at one of the treatment plants near Moscow reaches 9 m/hr with the efficiency of suspended matter removal about 90% and reduction of BOD$_5$ value over 70%. As working medium in this case use is made of 1-2 mm sand fractions with the height of layer 1.2 m and of 0.8-2.5 mm coal fractions, with the height of layer 0.6 m.

Utilization of specially prepared charge makes it possible to increase filter capacity and to achieve considerable treatment efficiency. For instance, investigations carried out by VODGEO have shown that the use of filter charged with polyurethane material (the size of particle about 1 x 1 x 1 cm, the height of the layer 1-1.2 m) provides the removal of oil products from a number of waste water categories by 90% with the rate of filtering being up to 20 m/hr.

Filtration of waste water as has been already mentioned can be in some cases combined with settling and flotation. The use of such installations is particularly efficient in systems of local installations and treatment of small amounts of waste water and provides reduction of required areas and reduces operational costs.

The processes and apparata touched upon in this report do not cover all types and structures of physicomechanical installations used for treatment of industrial and municipal waste water.

In spite of the fact that they are most frequently used in schemes of treatment plants and that considerable operation experience is available these installations still need further development both in respect of technological process improvement and design appearance.

In this connection attention should be paid in future to the following aspects:

- improving the existing installations for physical and chemical treatment, increasing their capacity and operational efficiency;
- creating combined settling installations which include filtration, flocculation and flotation zones;
- investigating new kinds of filtering charge for filters;
- designing new structures of settlers, flotators, centrifuges, hydrocyclones, filters to be used for intensification of process of magnetic and electric field, vibration, ultrasound etc.

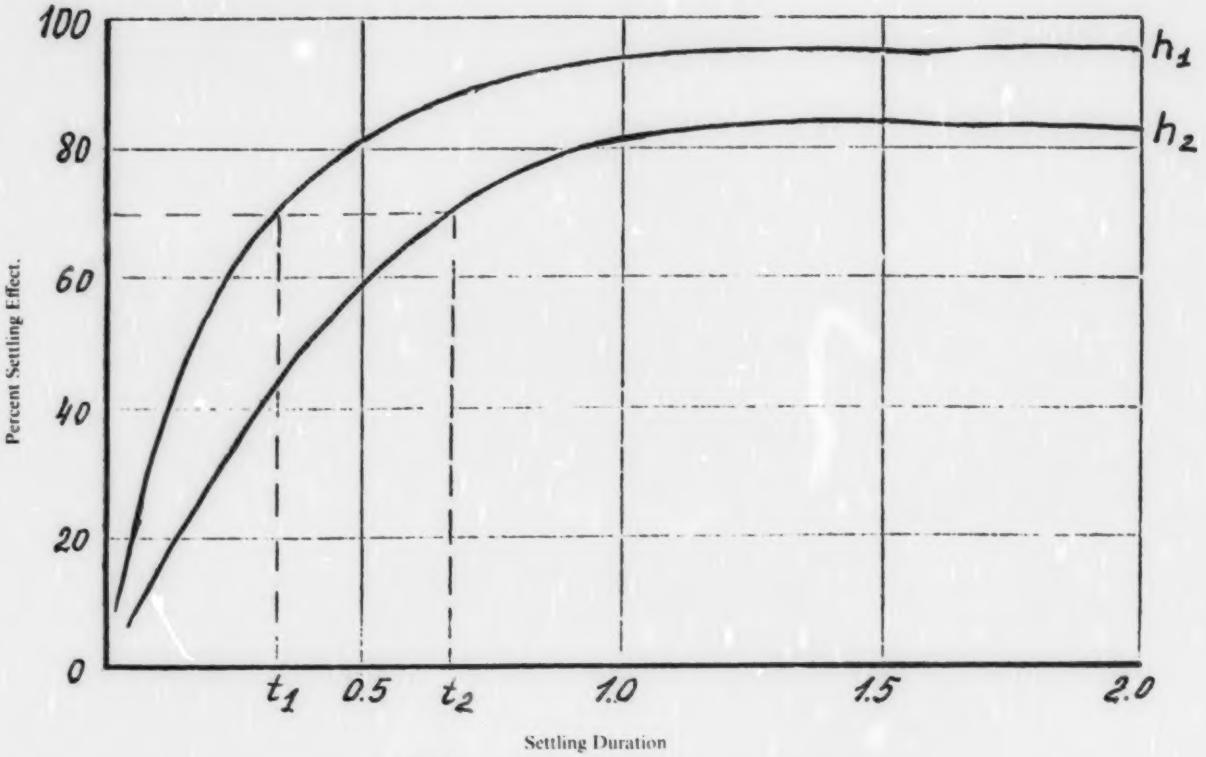

Figure 1.
**Kinetics of Insoluble Solid Settling**

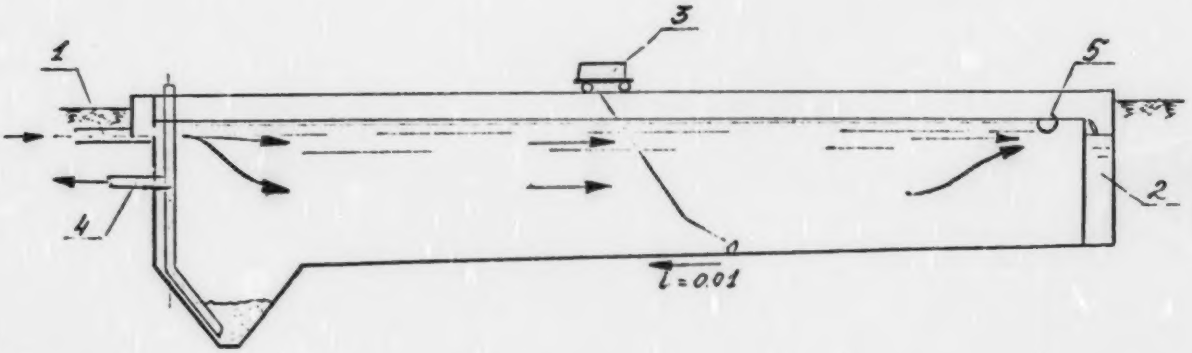

Figure 2.
**Horizontal Settling Tank**

1. Raw water inlet
2. Clarified water outlet
3. Scraping mechanism
4. Sludge drain
5. Grease Collected trough

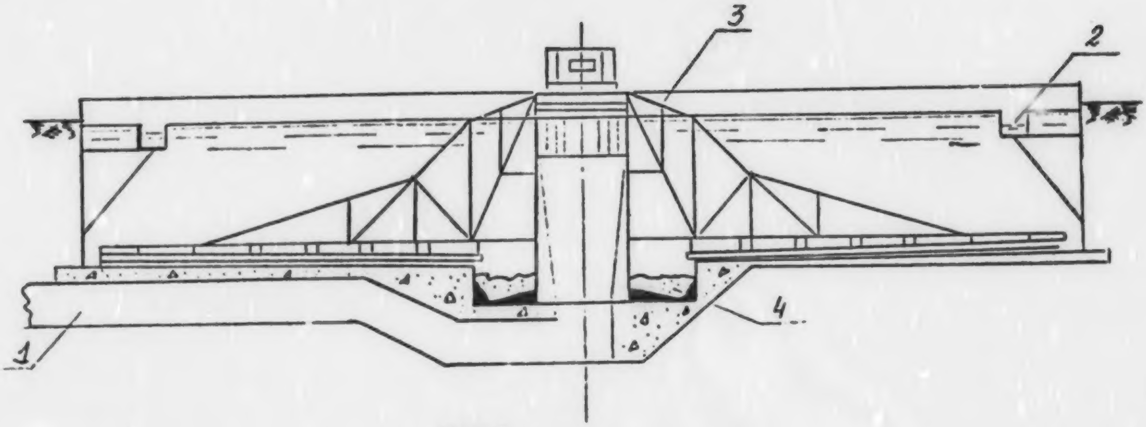

Figure 3.
**Circular Settling Tank**

1. Raw water inlet
2. Clarified water outlet
3. Scraping mechanism
4. Sludge drain

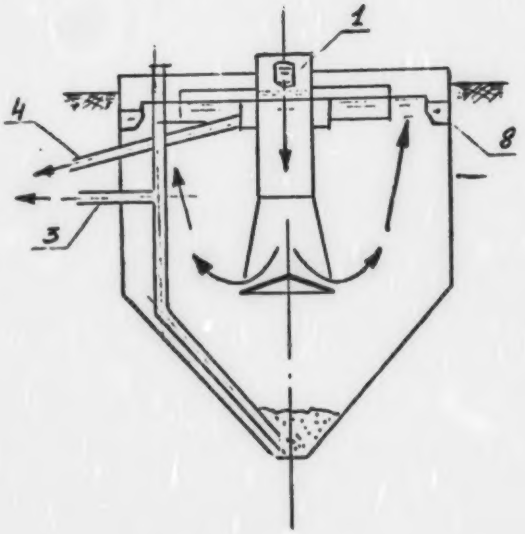

Figure 4.
**Vertical Settling Tank**

1. Influent trough
2. Effluent trough
3. Sludge drain
4. Floating bodies outlet

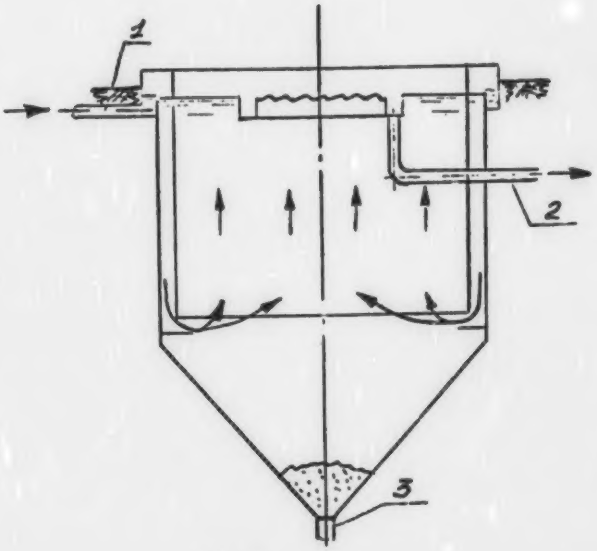

Figure 5.
**Vertical Settling Tank with Peripheral Inlet**

1. Raw water inlet
2. Clarified water outlet
3. Sludge drain

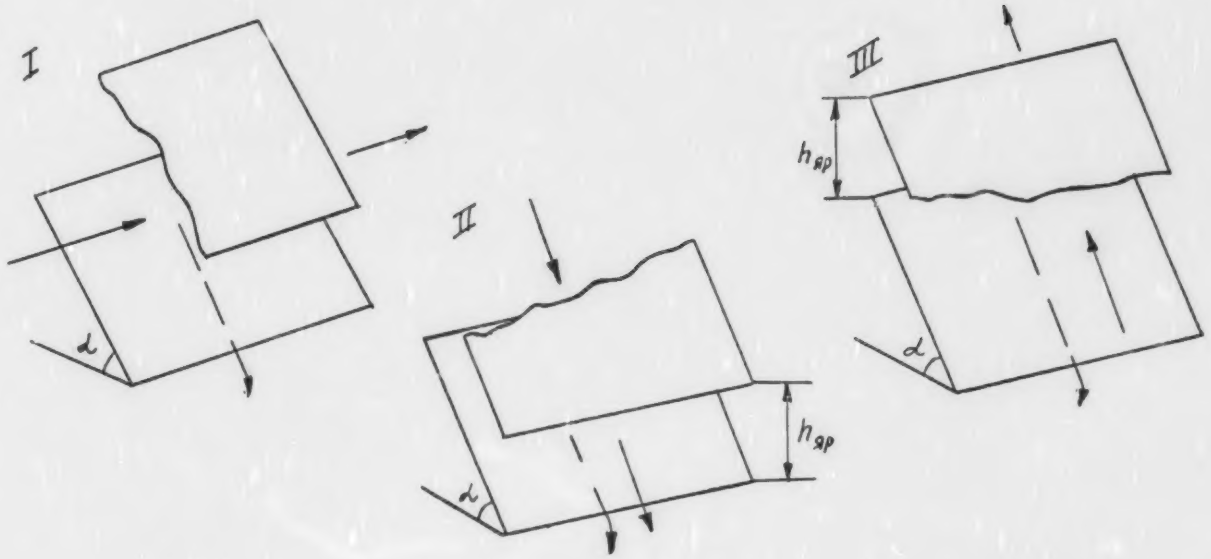

**Figure 6.**
**Scheme of Operation of Thin Bed Settling Tank**

1. Crossflow scheme
2. Uniflow scheme
3. Counterflow scheme

Direction of Water Movement
Direction of Sludge Movement

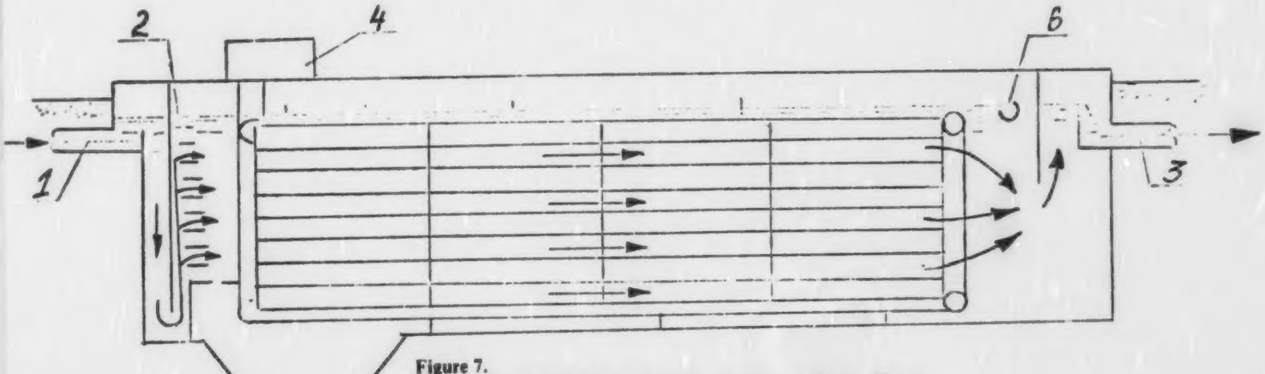

**Figure 7.**
**Thin Bed Settling Tank of Crossflow Type**

1. Raw water inlet
2. Water proportioned distributor
3. Clarified water outlet
4. Scraping mechanism
5. Sludge Drain
6. Grease collected trough

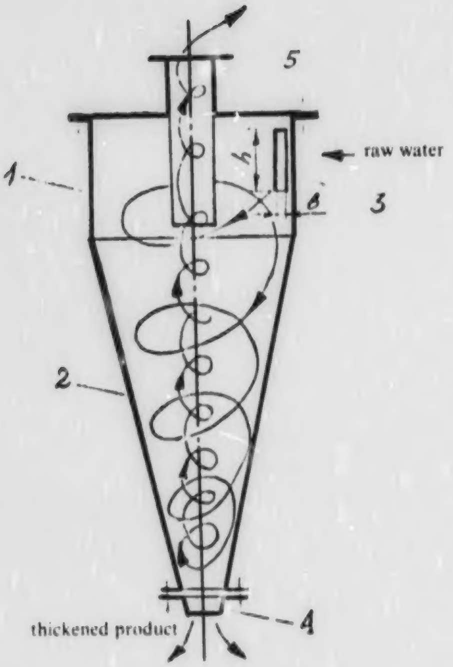
5
raw water
h
b
1
3
2
thickened product
4

**Figure 8.**
**Pressure Hydrocyclone**

1. Cylindrical part
2. Conical part
3. Discharge nozzle
4. Slime nozzle
5. Overflow nozzle

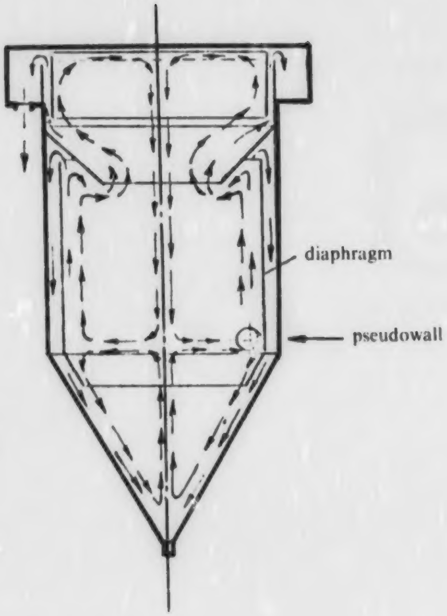
diaphragm
pseudowall

**Figure 9.**
**Open Hydrocyclone**

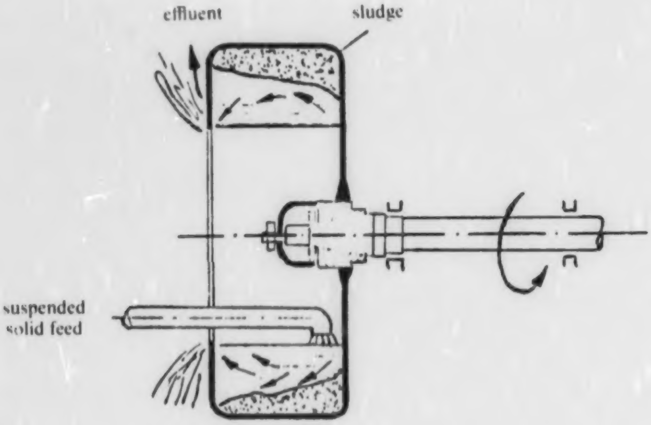
effluent
sludge
suspended solid feed

**Figure 10.**
**Sedimentation Centrifuging with Continuous Suspended Solid Feed and Periodical Sludge Discharge**

# Physical Treatment of Oil Refinery Wastewater*

**William J. Lacy, P.E.****

## Introduction

The treatment of oil refinery process wastewaters usually involves a series of process steps as shown in Table I.

This paper will be divided into two parts the first part defines physical treatment processes, i.e., gravity separation, stripping, solvent extraction, adsorption, combustion, and filtration. The second part of the paper describes an Environmental Protection Agency demonstration project on a actual refinery effluent water treatment plant using activated carbon.

As background physical treatment data on refinery wastewater, let us compare several types of units under various loadings. Typical efficiencies of these oil separation units are shown in table II.

### Physical Treatment Processes

Physical treatment processes commonly used in treatment of refinery wastes include gravity separation, flotation, stripping processes, adsorption, extraction, and combustion. The waste from a refinery plant may require a combination of these processes.

**Gravity separation** includes the removal of materials less dense than water such as oils and air-entrained particulates by flotation and the removal of suspended materials which are more dense than water by sedimentation. Sedimentation and flotation techniques commonly use chemicals to enhance the separation process. Wastewaters often contain quantities of free and emulsified oil which must be removed prior to subsequent treatment. Free oils are much easier to remove if their concentration is high. Slop oils that are recovered by the separation process can be cleaned and reused.

The most commonly employed separator design is that presented by the American Petroleum Institute. Although some reduction in chemical oxygen demand (COD) can be expected due to removal of oils and tars, little or no biochemical oxygen demand (BOD) removal will be prevalent.

Oil emulsions are the major problem of oil-water separation. Emulsifying agents prevent the oils from coalescing and separating from the water phase. Emulsifying agents are surface-active agents and include catalysts, the sulfonic acids, naphthenic acids, and fatty acids, as well as their sodium and potassium salts. In an alkaline medium, calcium and magnesium salts form finely divided suspended solids which stabilize the emulsions.

To separate the emulsified oils from the wastewater, the emulsion must be broken. The application of heat and pressure is the more effective method used in de-emulsification of a waste. Distillation methods, are also effective in breaking emulsions as are filtraton, acidification, and electrical methods.

Sedimentation in the pre- or primary treatment of refinery wastes with high suspended solids concentrations, in secondary clarification, and for sludge thickening. Wastewaters high in collidal material must be chemically treated before adequate separation by sedimentation can be obtained. The removal of solids and oils from wastewaters and the concentration of sludges can be accomplished using air flotation.

Gravity oil separators usually precede flotation units in most industrial applications. One advantage of flotation over sedimentation is the shorter detention time required to clarify a waste by flotation, resulting in a smaller unit.

**Stripping processes** are used to remove volatile materials from liquid streams. These methods are employed generally to remove relatively small quantities of volatile pollutants from large volumes of wastewater. Stripping is a low-temperature distillation process whereby reduction of effective vapor pressure by the introduction of the stripping medium replaces the high temperature requirement. The two types of stripping agents commonly used are steam and inert gas.

The stripping of hydrogen sulfide and ammonia from sour water is the most common use of stripping. Stripping agents used to remove these contaminants are steam, natural gas, and flue gas. Phenols can be removed from aqueous waste streams by steam stripping which is applicable when a wastewater is subject to short variations in termperature, specific gravity, phenol concentrations, and suspended solids.

The stripping rate is a function of temperature, the stripping gas flow rate, and tank geometry. Laboratory testing has indicated that most of the BOD removal during the stripping of biodegradable volatile organic compounds was the result of biological action rather than physical stripping.

**Solvent extraction** methods utilize the preferential solubility of materials in a selected solvent as a separation technique. The criteria for effective use of a solvent in wastewater treatment include (a) low water solubility, (b) density differential greater than 0.02 between solvent and wastewater, (c) high distribution coefficient for waste component being extracted, (d) low volatility and resistance to degradation by heat if distillation is used for regeneration or low solubility in liquid regenerants, and (e) economical to use. Equipment used for extraction of wastewater include counter current towers, mixer-settler units, centrifugal extractors, and miscellaneous equipment of special design.

**Adsorption** is the process whereby substances are attached to the surface of a solid by electrical, physical, or chemical phenomenon. A carbon medium has been the most successful adsorbent in removing certain refractory chemicals from wastewaters. Phenols, nitriles, and substituted organics are also adsorbed by carbon when present in low concentrations.

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*To be presented at the Joint US-USSR Symposium on Physical Treatment held in Cincinnati, Ohio, April 5-6, 1977.

**Principal Engineering Science Adviser, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C. 20460

**Combustion** processes are feasible for disposal of some refinery wastes which may be too concentrated, too toxic, or otherwise unsuitable for other methods of disposal. Combustion may be either direct or catalytic, depending on the waste to be oxidized.

Submerged combustion has been used successfully in the total or partial evaporation of waste streams as well as concentrating dissolved solids. This method produces an effluent which either has reuse value or which is easier to dispose of than large volumes of the liquid waste. Incineration is the commonly used combustion process for refinery wastes. Fluidized bed incinerator can be used for burning oily sludges. The fluidized bed incinerator provides better controlled combustion with lower requirements for excess oxygen than conventional incinerators for oily sludges. Incineration occasionally converts a water pollution problem into an air pollution problem.

**Filtration** processes are used to remove and concentrate solids on oily materials from a waste stream. A filter can be specifically designed to remove small quantities of these materials as a final step in wastewater treatment, or it may be used to concentrate a waste so that further treatability of wastewater will be enhanced. A polishing filter employing sand filtration can be used to remove additional suspended material.

## EPA Demonstration Project

Petroleum refineries are faced with the problem of disposing of hugh volumes of wastewater. These large amounts of water come from a wide variety of sources. Sources include process water used for heat transfer, wash water, and rain runoff which collects oils and chemicals from within the refinery.

Separation of the visible, floatable oils was considered satisfactory to allow discharge into adjacent waterways. To protect our waterways from these harmful discharges, new and improved technology is needed.

One major pollutant existing in refinery discharge waters is the oxygen demanding material. Oxygen demand, by chemicals and oils lowers the water's available dissolved oxygen content, a vital need for marine life.

The US EPA awarded a $274,719 grant to Atlantic Richfield Company as the government's share of a $1,159,584 project (28% of cost) at the Watson Refinery in Los Angeles. Atlantic Richfield Company's Watson Refinery is one of about 16 industrial facilities discharging water into the Dominguez Channel. The Water Refinery was limited to 1000 kg per day of COD in its discharge water to the Channel. Meeting this requirement meant reducing the COD in its discharge waters by 95% if the water was discharged to the Channel.

The Watson Refinery made an agreement with the Los Angeles County Sewer District to put its process wastewater through the County's primary treatment unit. Due to hydrolic limitations in the unit, the County was unable to handle rain water runoff.

During periods of rainfall, the process wastewater and rain water mixture which were interconnected could not be sent to the sewer district facilities due to the presence of rain water, nor could it be sent to the Dominguez Channel due to high COD from the process wastewater. A system was needed which would treat all the process water plus rain water as it was produced, or an impounding plus processing system which would allow large volume impounding during the rain followed by low volume processing. A system was needed which could be started up easily when rain fell and shut down when not required. Biological units require continuous feed, therefore, conventional technology was not satisfactory. It was decided to use impounding followed by activated carbon treatment to adsorb the COD material from the impounded rain diluted process water.

Construction of the first commercial sized carbon adsorption plant for treatment of petroleum refinery wastewater was completed in 1971 and contained over one-half million pounds of activated carbon. Activated carbon was used during the two-year project to adsorb organic chemical oxygen demand materials from the impounded rain water and process water mixture. The adsorbent carbon used is a granular activated carbon of 8 to 30 mesh made from bituminous coal. It has high hardness standards to minimize attrition loss in handling, regeneration, and hydraulic transport. It has a broad spectrum of pore sizes to meet adsorption requirements for a broad range of organic molecule sizes.

### Thermal Regeneration

The carbon is regenerated by selective oxidation of the organic impurities in the pores, at high temperatures (900°C - 970°C) and with a controlled low oxygen atmosphere in a multiple hearth furnace. As the carbon is heated, the more volatile organic compounds are vaporized. With further heating, additional organics are pyrolysed. The remaining organics are then oxidized selectively by addition of air. The carbon is then quenched in water. Time, temperature, and atmosphere are the controllable parameters for regeneration. Free oxygen must be carefully controlled in the lower hearths of the furnace to avoid burning up the regenerated carbon.

### Chlorination

Chlorine can be added to the effluent stream to permit operating the carbon beds with some breakthrough of organics because chlorine will reduce organic COD level as well as inorganic. This provides greater flexibility in loading the carbon or in handling an unusual COD load.

**Description of Activated Carbon Plant**

The water treatment facility is made up of four main systems plus an impounding reservoir. Figure 1 describes this system.

**Reservoir**

The reservoir is a 1.2 million barrel holding basin which impounds all refinery wastewater and rain water runoff when the Los Angeles County Sewer District cannot accept it.

**Water Treatment Carbon Adsorption Unit**

The water treatment unit is shown in Figure 1. This unit reduces the organic COD of water impounded in the refinery prior to discharge to the channel. The water treatment unit consists of twelve identical adsorber cells, (V-1 through V-12) each 3.7m x 3.7m metric 1 x 7m deep. Each cell originally contained a 4m deep bed of carbon having a dry weight of approximately 22,100 kg. Supporting the carbon bed is a one-foot layer of gravel on top of a Leopold underdrain system. The depth of the carbon was altered in 1972 for reasons discussed later in this report.

Impounded water is delivered to the influent water distribution trough through a 35cm line from the impounding reservoir. The water is distributed to any or all of the twelve adsorber cells (V-1 through V-12) by slide gates. Flow to each cell is regulated by a handwheel operated slide gate.

The regeneration furnace is a 140cm I.D., six hearth multiple hearth unit. A diagram of the furnace is shown in Figure 2. It is gas-fired on two hearths. A center shaft rotates arms with teeth which move the carbon across the hearths and downward through the furnace. The burners on the furnace automatically control furnace temperatures at the desired levels via thermocouple element and controllers. Steam and air addition rates are manually set.

The afterburner section is separately gas-fired to raise off-gas temperatures to about 800°C. This is required to combust organic vapors in the furnace exit gas.

The hot gas from the after burner goes through a quencher and is cooled by water injection; is pulled through induced draft fan (K-4) again with water injection for scrubbing, and exits through an entrainment separator where entrained water and particulate matter scrubbed out of the off-gasses are removed. The clean flue gases are exhausted via stack to the atmosphere. Hot air from the center shaft is added to the stack to reduce the humidity and minimize the vapor plume.

Regenerated carbon discharges down a chute from the furnace in periodic slugs as the rabble arms pass over the drop hole on the bottom hearth. This chute has two legs. Normal carbon flow is vertically into the quench tank (V-19). Water level in the quench tank is kept above the bottom of the Chute to prevent air from being drawn into the furnace. A trash screen is provided in the quench tank to protect the eductor.

The 45° legal on the furnace discharge chute is used to bypass the quench tank in case transfer problems are encountered. Opening the dump gate permits hot carbon to drop directly into drums and allows continued furnace operation.

Water sprays are provided to quench the hot carbon to eliminate sudden evolution of steam which would upset furnace pressures. Quenched carbon is stored (V-17) until needed for refilling an adsorber cell.

**Design Basis**

The volume of carbon in the adsorbers and its exhaustion rate are set by the volume of wastewater to be treated, the concentration and types of adsorbable material in the influent, and the permissible COD concentration in the effluent water. Design of the full scale unit was based on pilot tests performed on diluted refinery wastewater.

The carbon exhaustion rate was difficult to establish from the pilot plant tests because the influent COD concentration varied considerably, both above and below the limits expected under actual operating conditions. The actual design of the unit was based on the following criteria:

30 days per year of rain (maximum)
300,000 barrels water per rainy day (maximum)
9,000,000 barrels of water per year (maximum)
250 ppm COD average influent concentration
37 ppm COD average effluent concentration
500 grams of carbon exhausted per 1000 gallons water treated

The unit was designed to handle 100,000 barrels of water per day. Thus, the unit would run 90 days if the maximum rains were received without having to replace or regenerate any carbon. Based on this operation premise, regeneration of all carbon would be done during the summer, non-rainy season. The regenerator furnace was designed to regenerate 3,900 kg pounds of carbon per day. This is equivalent to 11.3 GPM of slurry from V-18. The approximate utility consumption, based on design, was as follows:

Steam - 1kg of steam per kg of carbon = 320 kg hr.
Refinery fuel gas (including after burner) = 3,000 SCFH

**Quantities and Costs Based on Conditions During the Project**

During the two-year project, 172,040,000 gallons of water was processed to load 747,000 kg of carbon with 165,000 kg of COD. This resulted in an average carbon loading of 100 grams of COD per 400 grams of carbon. The Carbon was used at the rate of 4.5 kg per 1000 gallons of water treated. The average feed COD was 249 ppm and the average effluent was 50 ppm. Averaged data for each of the three periods of operation is given in Table 9.

The data in Table III shows that the second rains single stage operation had a slightly higher loading than the first rains single stage operation, and a lower effluent COD.

The overall average cost to operate the

plant was 49C per 1000 gallons of water treated, or 524 kg of COD removed from the water.

With the improved operation of the second year, the plant demonstrated the ability to operate at 40¢ per 1000 gallons of water treated, or 40¢ per kg of COD removed.[1]

It might be noted that oil refining is the most capital-intensive industry in the U.S. with an investment of $108,000 per employee, according to the Conference Board, a private group. Least capitol-intensive is the apparel industry which has about $5,000 invested per employee.

In closing, let me point out that environmental expenditures are on the increase in all nations of the world. In table IV, it is shown that the cost for environmental control for all U.S. industry was reported by *Chemical Week* magazine, May 1976 issue, to be 17.1 billion dollars to meet the EPA 1976 regulations. The cost to the U.S. petroleum industry is 2.1 billion dollars. Data on the USSR, Japan, and Sweden are also included in the table for comparison.

There is little doubt that environmental protection will cost both in money and energy; but the price will be paid either by money or by degradation of our environment, and even out health. A balanced approach by all nations is the desired goal. This symposium is one of the ways of achieving this goal.

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[1] *Additional detailed data on this project can be found in an EPA Report #660/2-75-020 entitled "Refinery Effluent Water Treatment Plant Using Activated Carbon," June 1975*

# Improvement of Hydraulic Conditions of Radial Settling Tanks

**Skirdov I.V.**
All-Union Scientific-Research Institute "VODGEO"

Radial settling tanks have found a wide application in the waste water treatment practice. This type of installation is successfully used for purification of municipal and industrial wastes, which nature, concentration and granulometric composition of suspended solids (SS) vary within a wide range.

Radial settling tanks are mainly used for clarification of recirculating waters of blast furnace gas scrubbing, conveyer wastes of sugar mills characterized by a high content of SS. But they are practised on the largest scale in the field of municipal sewage treatment at treatment facilities of medium and high capacity.

In spite of the fact that the field of application of rectangular settling tanks extends due to the tendency to combine installations in one unit and thus to save required spaces, radial settling tanks still remain the most advantageous and profitable for use at large treatment facilities.

Though the hydraulic conditions of rectangular settling tanks are somewhat better than those of radial ones, the latter have indisputable advantages over rectangular settling tanks, as the design of scraping devices of radial settling tanks is more simple and reliable in operation than any of known modifications used in rectangular settling tanks.

Besides, the circular configuration of the basin provides greater strength of outside walls and considerable saving of building materials.

The most serious of them is a relatively low efficiency of the volume usage. According to experimental data obtained by different authors this value ranges from 30 to 60 per cent and averages 45 per cent (1).

When influent enters the central part of radial settling tanks and moves towards the periphery the expansion of the working jet takes place causing its hydrodynamic instability. Under these conditions the working jet is subjected to dense circulation and turbulent pulsations preventing the volume of the tank from being used effectively.

Various modifications of distributing devices located in the central part of the tank cannot significantly improve hydraulic conditions of radial settling tanks. In most cases the expansion of the areas required by collecting devices has appeared to be even less effective as the obtained result is not worth the complication of the design.

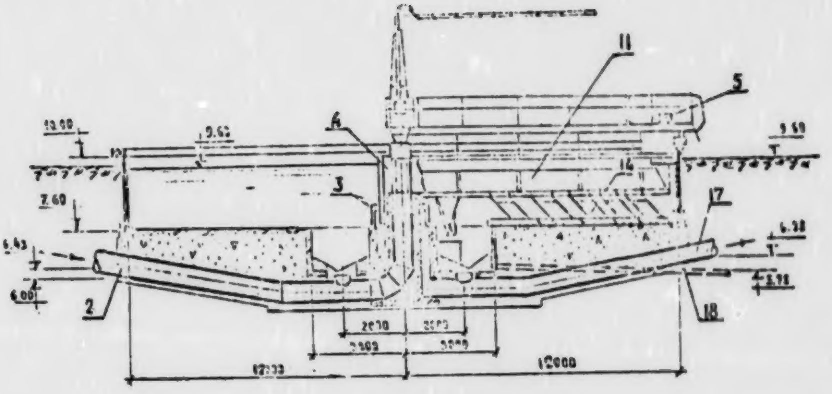
Inlet of the influent from the periphery turned out to be rather effective (2). Rapid reduction of the feeding velocity followed by the slow speeding-up of the flow which are characteristic of these conditions, have increased the stability of the working jet. The investigations have shown that the advantages of this way of the influent distribution diminish as the dimensions of the installation increase.

At present radial settling tanks with peripheral inlet are being tested in operation.

Large sizes of collecting devices as well as their complexity are among serious shortcomings of radial settling tanks. For example in large installations (40 m in diameter) the length of water collecting troughs and weirs which manufacturing is very labour-consuming, amounts to hundreds linear meters.

In settling tanks with peripheral inlet the same difficulties take place during installation and operation of water distributing devices.

A new type of the radial settling tank has been recently used in the Soviet Union. The water distributing device of the tank is


11
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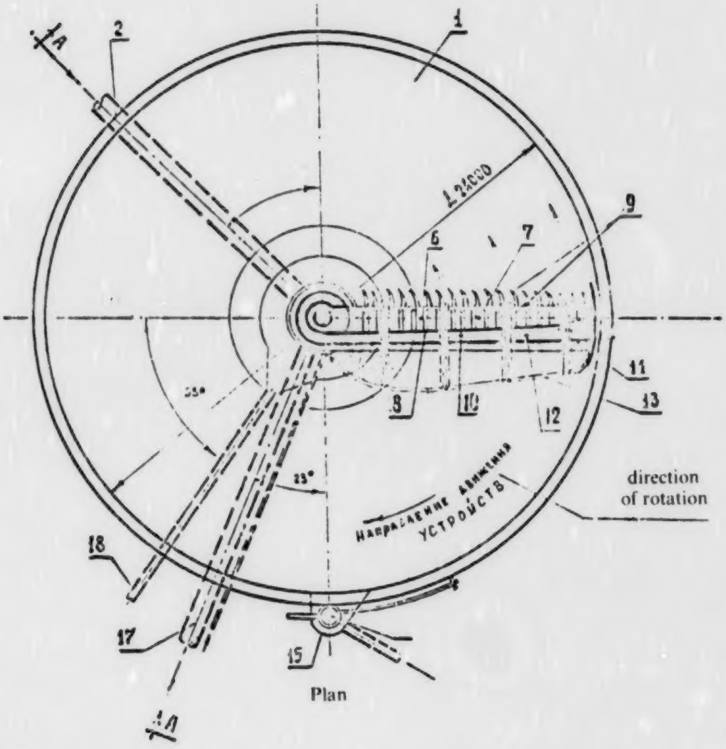
Section A-A


1A
2
1
⌀ 24000
6
7
9
8
10
12
11
13
55°
25°
Направление движения устройств
direction of rotation
18
17
15
1A

Plan

**Figure 1.**
**Settling tank with rotating distributing arm.**

continuously rotating together with the scraping arm. The design of the tank was developed at VODGEO Institute (3), the project was madeout at Sojuzvodokanalproject Institute.

General view of the settling tank is represented in Fig. 1.

The basin of the settling tank has circular configuration similar to that of radial tanks. Influent pipe (2) passing to the central part of the tank is conjugated with the central part (4) of the distributing device with the help of air valves (3). This device is connected with the sludge scraping arm (5) and rotates around the central axis. It consists of distributing trough (6) furnished with the slotted bottom (7), a baffle (8) and a series of jet guiding blades (9). The distributing trough is conjugated with the collecting trough (10), comprising the weir (11) and the solid bottom (12).

In front of the weir (11) there is the half-submerged baffle (13) for collection of the floated matter.

The scrapers (14) are hung up to the bottom part of the distributing trough by means of hinges. A chamber with submerging funnel (15) for removal of floated matter is envisaged at the side wall of the settling tank's basin.

In the central part of the settling tank there is a sludge collecting hopper (16). Clarified effluent and sludge are removed through pipings (17) and (18).

The settling tank with the rotatory distributing device operates in the following manner: The influent enters through the piping (2) to the central part of the settling tank (4) and then to the distributing trough (6). By means of the baffle (8) and blades (9) water is directed to the spaces between the blades and comes out to the settling tank. Distribution is carried on in such a way that detention times for each separate jet are equal, that is the flow from the trough to the settling tank is increasing from the centre to the periphery. The collection of the clarified effluent is carried on the same way.

The slots in the bottom (7) of the distributing trough prevent the sand and other heavy solids, dragged along the bottom from being collected in the trough.

When the distributing device moves in the direction opposite to the direction of the water, flowing out of it, reduction of the flow rate in the settling tank occurs. If velocities of the water exhaust and the distributing device rotation are equal the state close to the static is observed in the settling tank.

The attention should be paid to the fact that by changing rotation speed of the distributing device one can regulate the velocity of the water movement in the settling zone irrespectively of the wastes' flow and thus to create optimum conditions with due regard for settling properties of SS.

In the outlet zone a slight turbulence of the flow is observed promoting the flocculation of suspended solids, but soon it fades and sedimentation of the suspension occurs. The layer of clarified effluent is collected by the moving water-collecting device. Having flown over the weir edge (10) the clarified effluent flows along the trough (9) to the central part and then is withdrawn through the pipe (17).

Air valves (3) provide conjugation of rotating and fixed units of the central part of the distributing device and safely isolate the clarified effluent from feeding and detained influent.

Settling tanks with rotatory distributing devices operate at a number of industrial and municipal treatment facilities (Fig. 3).

The experience of their exploitation permitted to make some general conclusions and to compare their operation with that of conventional radial settling tanks.

Graphical form of the relationship between the hydraulic particle size of suspended solids and the hydraulic load is given in Fig. 2. This relationship allows to compare the efficiency of facilities operating under different conditions.

It follows from Fig. 2 that with equal efficiencies of clarification, that is with equal values of hydraulic particle size of captured suspended solids, settling tanks with the rotatory distributing devices provide higher hydraulic load, 1.4 — 1.6 times exceeding the load on radial settling tanks.

At technological calculation of settling tanks one should also take into account hydraulic particle size of settled suspended solids. Besides, the degree of the hydraulic perfection of the installation should be also taken into consideration. It may be characterized by the coefficient of the volume usage.

The following relationship is valid for radial settling tanks:

$$R = \sqrt{\frac{Q}{3.6\pi K U_o}} M \ . \qquad (1)$$

where $Q$ — calculated water flow, m³ hour

$K$ — coefficient of the volume usage
for radial settling tanks $K = .045$
for settling tanks with rotatory distributing device $k = 0.85$

$U_o$ — hydraulic particle size of retained suspended solids, mm c

In its turn $U_o$ is characterized by settling properties of SS and by the depth of the continuous-flow part of the settling tank — H:

$$t = \frac{1000\, K\, U_c}{t\left(\frac{KH}{h}\right)^n} \qquad (2)$$

where $t$ — is the detention time for the influent in the cylinder no less than 160 mm in diameter, with the water layer h, corresponding to the given clarification efficiency. This parameter is determined experimentally for a concrete waste water;

$n$ — a factor characterizing gravity coagulation of SS.

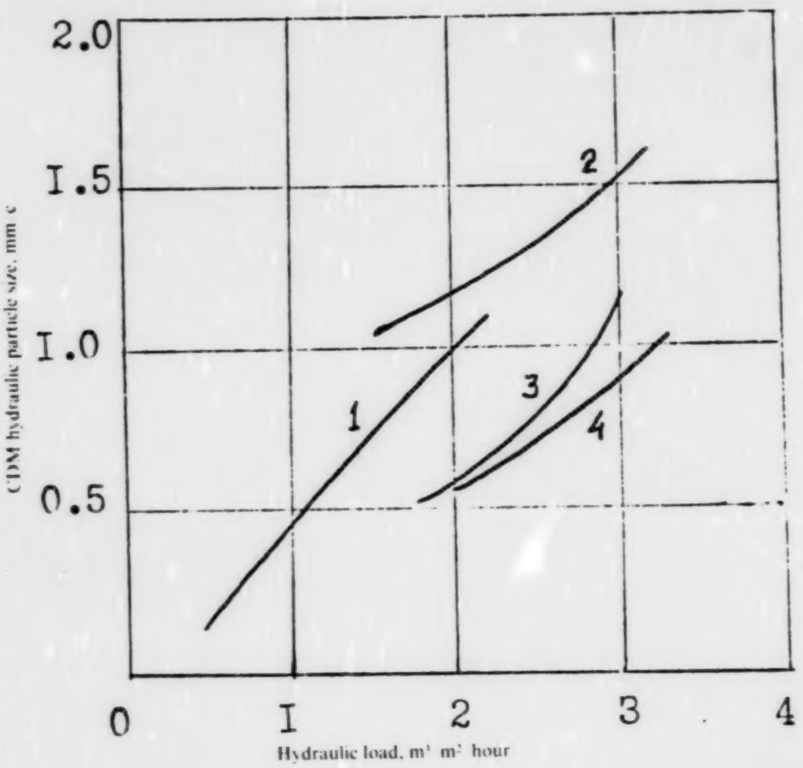


Figure 2.

**Dependence of the CDM hydraulic particle size on hydraulic load for different types of settling tanks:**

1. radial settling tanks, D = 33 m;
2. radial settling tanks of 40 m diameter;
3. settling tanks with rotating distributing devices, D = 33 m;
4. settling tanks of the same type, D = 20 m.

---

The value of n is determined experimentally at varying the water layer in the cylinder h.

For municipal wastes n = 0.25;

For heavy mineral particles of SS n = 0.4 0.6.

H calculated depth of the continuous-flow part of the settling tank: with the rotatory distributing devices H = 1 1.5 m; for radial settling tanks it is assumed to be equal to 3 3.5 m.

For settling tanks with the rotatory distributing devices the period of rotation of the sludge scraper and distributing devices must be connected with the output:

$$T = 0.667 \frac{HD^2}{Q},$$

where T — the period of rotation of a distributing device, hours;

H — the depth of the settling zone, m;

D — diameter of the settling tank, m;

Q — waste water flow, m hour

It should be noted that normal hydraulic conditions in these installations cannot be observed if the difference between the density of the influent and the density of the clarified effluent is great, so the application of settling tanks with the rotatory distributing devices is limited by the SS concentration of the influent up to 500 mg l.

At present modifications of the settling tanks with the rotatory devices, permitting to eliminate this kind of limitations are being tested in the full-scale operation.

Due to the effective reduction of the influent velocity the depth of the protective zone in the settling tanks with the rotatory distributing devices can be reduced to 0.7 m and thus the total depth of the installation can be reduced to 2-2.5 m, that is half as many as the depth of conventional radial settling tanks.

## Conclusions

**1.** Radial settling tanks have significant advantages over other types of settling tanks and are widely used at large treatment plants.

**2.** Hydraulic conditions of conventional radial settling tanks do not ensure the effective use of the volume of these installations.

**3.** The application of the rotatory distributing devices allows to improve hydraulic conditions, to increase the load on the installation about 1.5 times and significantly reduce the depth of the tank.

**4.** Rotatory distributing devices allow to control the hydraulic conditions of settling tanks and their development and application for the mechanical waste water treatment is very promising.

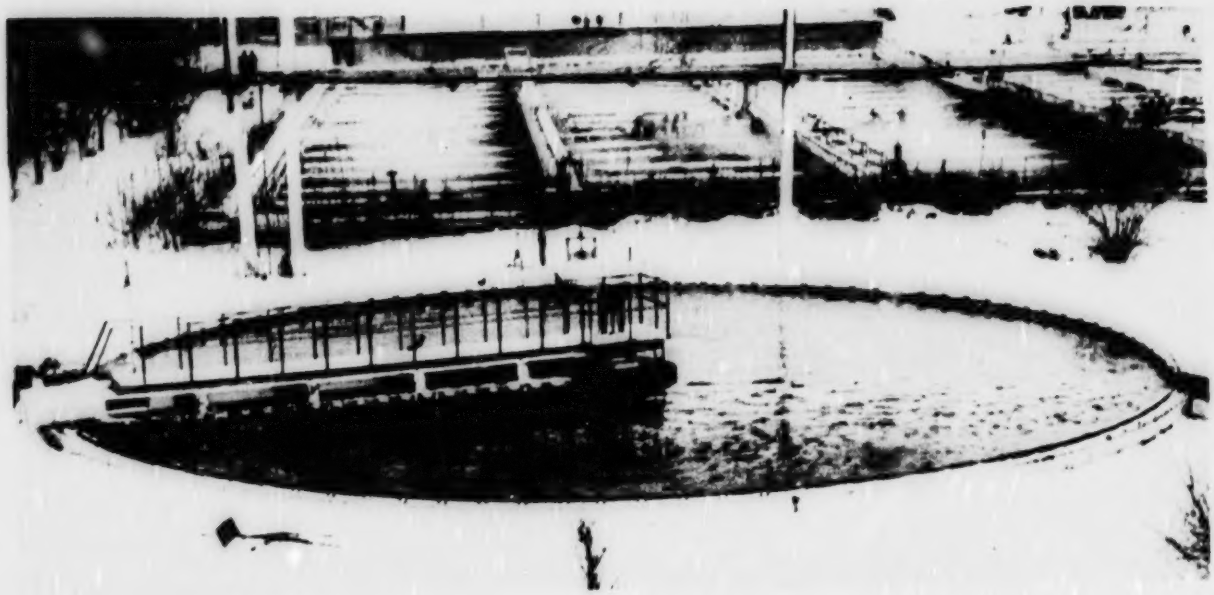


Figure 3.
**Functioning settling tank with rotating distributing arm. The view on the side of distributing grid.**

# Current Status and Directions of Development of Physico-mechanical Effluent Treatment in the Paper Industry

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## Introduction

At the previous conference in this series I reviewed the then current areas of application of physico-chemical effluent treatment in the paper industry. These included (a) chemical assistance to physical separation processes, (b) use of chemical reactants to remove undesired effluent constituents, and (c) physical treatment to remove specific chemical constituents as in steam- or air-stripping of pulping liquor evaporation condensates. The impetus for further development work and technology application in these areas was considered and a number of areas were proposed for possible cooperative study (1).

The objective of the current paper is to review this same general area, omitting, however, those developments and technologies that are dependent on chemical addition and readily identifiable chemical reactions as the basis for their effectiveness. In a sense then, physico-mechanical treatment is viewed as a subset of physico-chemical treatment, generally stemming from the same objectives but omitting the use of chemical additives or processes. The review is general in character, leaving both detailed examination of the reports cited and further cooperative activity in specific areas of mutual interest as the means for deeper exploration of specific findings.

Three areas of physico-mechanical treatment are addressed below and are identified as follows:

1 clarification of untreated or biotreated mill effluents dy gravity separation or media filtration,
2 in-process use of physico-mechanical treatment for improved water economy and organic load reduction,
3 dewatering and disposal of effluent treatment sludges.

The objectives of such treatment are numerous and include the following:
(a) effluent clarification in preparation for discharge or secondary treatment, or following secondary treatment,
(b) improved sludge dewatering and further disposal, (c) enhanced opportunities for wastewater reuse in papermaking through removal of suspended matter and objectionable organic constituents,
(d) relief of overload conditions at biotreatment facilities, (e) reduced possibilities for odor emission at biotreatment facilities, and (f) economic and technical optimization of wastewater management systems.

## Clarification of Untreated or Biotreated Effluents by Gravity Separation or Media Filtration

Within this general category the objectives differ somewhat, hence each area of clarification is considered separately.

### Clarification of Untreated Effluents

Clarification of mill effluents without flocculation chemical assistance is widely practiced as a preparatory step for biotreatment. The range of clarifier volumetric loading rates and removal of either total suspended or settleable solids for a variety of mill categories is reviewed in an earlier National Council report (2). An analysis of seven production unit categories indicated that average total suspended solids removal ranged from 70 to 93 percent. Settleable solids removal invariably exceeded 90 percent and commonly reached 95 percent. Reductions in BOD accompanying separation of the settleable solids depended on the relative contribution of those solids to the overall load, exceeding 80 percent for a group of non-integrated tissue mills and averaging 20 percent for integrated kraft packaging or newsprint mills. The survey at that time showed a median volumetric surface loading rate of 600 gallons/sq. ft./day, the level at which 95 percent settleable solids removal was considered achievable.

### Clarification of Biotreated Effluents

The two most commonly employed biotreatment processes either (a) have inherent clarification capability, as in the relatively quiescent zones between aerators in the longer retention aerated stabilization basins, or (b) provide such clarification through final clarifiers following activated sludge aeration or shorter retention aerated stabilization basins.

*1 Quiescent zone sedimentation in aerated stabilization basin systems* - A recent National Council report (3) provides the results of a detailed study of the mixing characteristics of a number of such basins. It defines the extent of those basin areas where mixer-induced velocities are lower than those needed to maintain biological floc particles in suspension. Such data provides a basis for determining when separate sedimentation basins or special exit area quiescent zones are needed for clarification of aerated stabilization basin effluents.

*2 Secondary sedimentation for activated sludge treatment systems* - Operational experience with such systems in the paper industry was recently examined at a National Council conference (4). While the norms of secondary clarifier surface loading design have been viewed as 700 to 1000 gal/ft$^2$/day, experience has shown that loadings exceeding 700 are incapable of adequately dealing with bulky sludges. There appears to be a growing view that loadings in the 400 to 500 range are better capable of accommodating process upsets. This subject is receiving further attention in attempting to deal with two separate but related questions, namely (a) how to maintain process integrity in the face of as yet incompletely controlled process load variability, and (b) how to achieve excessively restrictive governmental discharge permit requirements on effluent residual total suspended solids.

*3 Secondary flotation fo aerated stabilization basin effluent clarification* - One recent paper industry installation relies on air pressurized flotation to clarify the effluent from a six day aeration basin at a waste paperboard mill. While successful operation has been found dependent on addition of substantial alum coagulant to produce large size floc particles, the process is referenced here because it provided a more effective clarification alternative than use of a solids contact reactor. At temperatures above 60°F a 1 MGD flow from a 100 TPD mill receiving 140 ppm alum is clarified to an average residual TSS level of 24 ppm using a flotation tank unit loading of 3000 gal ft$^2$ day at 80 psi pressurization (5). Performance is, however, substantially lower during colder temperature periods. At temperatures averaging 51sF for the winter period the flotation-clarified effluent averages 65 ppm TSS.

*4 Media filtration of biologically treated effluents* - A number of recent inudstry studies have explored the capability of media filtration to clarify such effluents both with and without coagulant addition. One National Council study (6) conducted with bleached kraft mill effluent showed minimal clarfication capability unless coagulants were employed. Final TSS levels before and after coagulant addition were 116 and 42 ppm respectively. At the Great Northern unbleached kraft mill (7) granular media filtration was found capable of reducing TSS levels from 65 ppm (effluent from 14 days aeration) to 42 ppm without coagulants, and 36 ppm using 30 ppm alum. A recent study at the Buckeye Cellulose kraft dissolving pulp mill (8) showed that a biotreated effluent containing 32 ppm could be clarified to only 24 ppm without coagulants and 18 ppm using cationic polyelectrolytes at a filtration rate of 2 to 4 gal ft$^2$-min. In summary, it appears that granular media filtration is ineffective in clarifying aerated stabilization basin system effluents without coagulant addition, and only modestly so following such addition.

## In-process Use of Physico-mechanical Treatment for Water Economy and Organic Load Reduction

A major focus of the paper industry's current wastewater management technology development efforts involves in-process load reduction. Three such areas of activity are based on physico-mechanical approaches of widely divergent character, namely separation of fines and control of impurity buildup in whitewater system streams, air- and stream-stripping of condensates, and activated carbon adsorption of miscellaneous organic constituents. All are designed, however, to improve wastewater management practices by either volumetric or organic load reduction.

### White Water System Reuse Studies

The National Council has recently completed three studies (9) (10) (11) whose objective is to further the reuse of process wastewater in non-integrated paper mills. The program has proceeded in three phases as follows:

**a** the collection of information related to water reuse stressing operational limits to reuse related to changes in water quality,

**b** development of a computerized data retrieval system capability for entering new, and assessing existing information relating water quality and reuse potential,

**c** evaluation of the water renovation capability of new and proposed process equipment adapted to inclusion within the white water system.

The program has examined water reuse in the waste paperboard, fine papers and tissue towelling segments of the industry with the following results:

*1 Combination waste paperboard operations* - Studies at thirteen mills indicated that closure to 3000 gallons ton could be readily achieved without encountering serious water quality-related problems. Beyond that point piping system revisions and material changes were indicated to reduce corrosion and abrasion problems. Plugging at such points as pump packing gland seals, cylinder showers, bearing cooling jackets and machine felts was also encountered and attributed to fibre buildup in the recirculated water. The remedial approach has involved use of savealls, microstrainers, and fibre fractionators and concentrators. In-line slotted strainers are also gaining use.

Two recent reports document the utility of a 'float-wash' fractionator for assisting in achieving board mill water economy. According to Godin (12), water use and TSS losses at a board mill were substantially reduced by installation of a float-wash fractionator to allow recycle of board machine white-water to cylinder and felt showers. Holmrich (13) described such a proprietary device. Fractionation occurs by directing a stream against a screen and separating the long fibres from the fines with recycyle of the separated streams for various applications.

*2 Fine paper manufacture* - Twelve mills were examined in this study, all discharging less than 10,000 gallons ton effluent. Plugging problems at wire and head box showers, bearing cooling lines and on the machine felts have been dealt with by removal of long fibre material as in the board mills cited above. Felt hair removal is accomplished using horizontal rotating center-fed cylindrical screens of either nylon or stainless steel with a 120 to 140 mesh medium (14) (15).

In all but one of the mills visited fresh water was used for felt washing. This use remains as a large user of fresh water on the modern paper machine. While in the future it may be possible to reuse whitewater clarified by gravel filtration or other means for felt cleaning, tests carried out in mills forced to take this measure in times of extreme water economy indicate that premature deterioration of felts takes place (16). In the one mill visited which was using other than fresh water it was a 50 percent mixture of fresh water and dual media filtered clarifier water and they reported no loss of felt life using this mixture. In the use of stronger needled felts which are better able to stand up to high pressure water jets, the tendency today is to use high-pressure, low volume oscillating needled jet showers for intermittent felt cleaning. This significantly reduces water use.

*3 Tissue and towelling manufacture* - Twelve tissue and towelling mills were studied to determine current reuse capability, problem areas and opportunities for further water use economy. Of these, eight used less than 10,000 gal/ton while two fell below 2000 gal/ton. The problems retarding further use were similar to those reported previously; namely (a) increased line, nozzle, wire, and felt plugging, (b) scale and corrosion, (c) product color, and (d) slime accumulation.

The corrective measures of a physico-mechanical nature have emphasized improvement in in-plant flotation saveall operation, use of in-line strainers, and cascading of water use on vacuum pump systems to permit further use of clarified whitewater. The mill currently achieving the highest degree of closure, Kimberly-Clark at Fullerton, California (17) accomplishes this through use of bentonite flocculation- or lime softening-assisted diatomacious earth filtration, with the latter approach preferred.

**Condensate Stripping**

Progress has been recorded recently in this area for both kraft and sulfite liquor condensates as follows:

*1 Kraft condensate processing* - An early approach to condensate stripping for BOD load reduction was reported by Estridge (18) in which evaporator condensates, barometric condenser water and turpentine decanter underflow at an 850 ton per day linerboard mill were recycled to a cooling tower. Aeration of these process streams in this manner achieved a load reduction of 10,000 lbs BOD per day due almost exclusively to air stripping of methanol and other volatiles. An inherent drawback lay, however, in the transfer of odorous volatiles such as terpenes and organic sulfides to the atmosphere.

This deficiency has been met by systems employing either air or steam stripping with the stripped material being burned at a subsequent combustion unit. An example of such a system is that in operation at the Mead Corporation mill at Escanaba, Michigan. Initially this 800 ton bleached kraft mill installed a steam stripper handling hot water accumulator overflow, turpentine decanter overflow, evaporator condensates and miscellaneous hot odorous streams. The initial objective was to reduce odor release at the biotreatment system. This was accomplished using a fractional distillation column 53 feet high containing 24 trays, and steamed at a 2.5 percent rate, with non-condensibles and collected foul air burned in the lime kiln (19).

In 1973 a program was begun to determine whether the mill BOD load could be significantly reduced as well. Analysis showed that the stripper bottoms contained 15 to 18,000 lbs BOD daily and that 90 percent of this was accounted for by the methanol present in the condensates. Modifications to the system enable the steam feed to be increased to 8 percent so that the residual BOD was reduced to 4 to 5,000 lbs daily for a net reduction of 11 to 13,000 lbs daily. Total steam and power requirements are reported as 8000 lbs/hr of 60 psi steam and 65 HP for pumping condensates.

Kraft mill condensate stripping is now in use at seven United States mills. A recent report on this subject (20) reviews this technology and reports capital costs for systems ranging from air stripping through partial- to complete steam stripping at from 1000 to 5000 dollars per ton daily capacity, with comparable operating costs of 1.5 to 7 dollars per ton.

*2 Sulfite Condensate Processing* - Currently underway at the Flambeau Paper Company, Park Falls, Wisconsin sulfite mill is a project directed toward demonstrating the possibilities for recovering methanol, furfural and acetic acid as ethyl acetate from sulfite liquor evaporation condensates. The process being investigated involves steam stripping and activated carbon adsorption to achieve removal and separation of these components. This investigation expands on a project previously conducted at the Institute of Paper Chemistry (21).

Another treatment approach pertinent to sulfite liquor condensates involves the upward adjustment of spent liquor pH prior to evaporation so as to retain the volatile acids in the liquor concentrate, permitting their destruction in the liquor furnace rather than allowing their entry into the condensates. Previous studies have shown that upward adjustment of liquor pH from 2.5 to 4.0 could result in condensate BOD load reduction from 150 to 200 lbs per ton to 50 lbs per ton (22).

**Removal of Organic Materials from Paper Mill Effluents Using Activated Carbon**

Explorations of activated carbon treatment have been undertaken at a number of non-integrated paper mills involving in several instances combined treatment with municipal sewage. Included among these are (a) St. Regis, Bucksport, Maine, (b) Fitchburg Papers, Fitchburg, Massachusetts, (c) Mohawk Papers, Waterford, New York and (d) Neenah, Menasha, Wisconsin. Details of several such projects which follow indicate that chemical coagulation will generally represent an integral step in activated carbon treatment, if only to protect the carbon columns from plugging problems, but also to minimize the residual organic loading.

*1 Fitchburg, Mass.* - Pilot studies for a full scale project involving 14 MGD from two paper mills and 1.25 MGD municipal effluent were conducted using a process consisting of chemical coagulation with alum, sedimentation and activated carbon column treatment. Process results indicated an anticipated 50 percent BOD reduction through coagulation, followed by 82 and 86 percent reduction in COD and BOD passing through four carbon columns at 3.4 gal/sq. ft./min. The activated carbon process design criteria selected were 7.2 lbs carbon/lb BOD at exhaustion, 30 minutes contact time, and reactivation in a multiple hearth furnace. Costs were estimated at $2.1 million for construction of the carbon system in 1970, and $140,000 for annual operation, of which 70 percent is carbon makeup. The facility has been constructed, but operating results are not yet available (23).

2 *Neenah - Menasha, Wisconsin* - A pilot plant study was performed using municipal sewage containing 80 percent paper mill effluent. The process studied involved chemical coagulation with ferric chloride, sedimentation, high rate filtration at 12 gal/sq. ft/min. to remove fibrous material followed by a second filtration stage at 9 gal/sq. ft/min through PVC media, and upflow expanded bed filtration through 14-40 mesh carbon at 3 to 5 gal/sq. ft./min. Results obtained by the IPC study group indicated removals of BOD, COD and suspended solids prior to carbon treatment of 76, 83 and 98 percent respectively. Following carbon treatment, overall reductions were increased to 93, 95 and 99.5 percent respectively. Project costs were estimated in 1973 at 17 cents per 1000 gal capital and 35 cents per 1000 gal operating for a total of 52 cents per 1000 gal for a 10 MGD plant (24).

## Sludge Dewatering and Disposal

Sludge dewatering constitutes one area of extensive physico-mechanical treatment process involvement. This takes the form of the dewatering process itself, the impact of hydrous sludge presence on sludge dewatering, use of physical dewatering aids designed to dilute the presence of hydrous sludges, the potential use of thermal treatment to enhance dewatering, and the possibilities for physical separation of reusable materials from sludges. These subjects are considered below.

### Current Sludge Dewatering Practices

A recent National Council study (25) examined the extent of, and principal methods employed for mechanically dewatering treatment plant sludges. The study encompassed 15 percent of the mills operating in the United States and producing 35 percent of the industry's tonnage. Findings of the study can be summarized as follows:

1 The mechanical dewatering alternatives currently used in the pulp and paper industry (in the order of decreasing number of installations) include vacuum filters, centrifuges, V-presses, plate and frame presses, and screw presses. In the dewatering of sludges with ash contents of less than 40 percent vacuum filters outnumber centrifuges by a two-to-one ratio. On the other hand, at mills dewatering sludges with ash contents in excess of 40 percent centrifuges are favored by a ratio of two to one.

V-presses are utilized exclusively as second-stage dewatering devices while screw presses are being used for both first or second-stage dewatering. Second-stage dewatering is practiced by three-quarters of those mills incinerating sludge. Combined sludges containing up to 30 percent biological solids are being dewatered on vacuum filters, centrifuges and V-presses but at lower capacities, cake consistencies, solids recoveries, and higher conditioning costs than commonly encountered in primary sludge dewatering. Mills requiring cake consistencies of 35 percent or greater from combined sludges or 20 percent or greater from secondary sludges are frequently considering plate and frame pressure filtration.

2 Centrifuge capacities associated with pulp and paper industry primary sludge dewatering applications are hydraulically limited by acceptable solids recovery.

3 Scroll abrasion is the most commonly cited constraint to the continued application or extension of centrifugation for pulp and paper industry sludge dewatering. The only production categories where scroll lives between stellite resurfacing were reported to exceed nine months continuous operation were drinking mills manufacturing tissue and tissue mills generating sludges without pulp mill or flyash solids. In the absence of effective grit removal, scroll life for the balance has been limited to an average of 6 months.

4 Current advances in centrifuge technology have resulted in development of replacable conveyor tip wear plates which have exhibited the potential for superior wear characteristics, as well as reduced time requirements for resurfacing. The newer plates are in service at several mills. Their long term performance warrants attention of the industry to reevaluate the acceptability of centrifugation for sludge dewatering where circumstances and sludge characteristics suggest it to be a viable alternative.

5 Cake consistencies attainable by centrifugation or vacuum filitration of primary or combined sludges appear related to sludge ash content, cake consistency increasing with ash content among other variables.

6 Assuming the presence of adequate fiber, vacuum filter loading rates for primary sludges typically range from 5 to 10 lbs/sq ft/hr. Lower rates are common among nonintegrated mills and some groundwood operations. In those instances where chemical conditioning was encountered, it was practiced for improvement in solids loading rates, though increased solids recovery was an associated benefit.

7 Because of otherwise unacceptable cake discharge characteristics, the applicability of vacuum filters appears to be limited to those situations where 100-mesh fiber exceeds 10 to 20 percent of the sludge mass. A higher threshold is likely for combined sludge dewatering. Deteriorating filter performance can be anticipated as greater fiber recovery results in sludge fiber contents approaching that threshold.

8 Vacuum filter primary sludge solids recovery is influenced by sludge ash content and any chemical conditioning that might be practiced. In the absence of conditioning, increases in ash content are often reflected in less solids recovery.

9 Fabric media vacuum filters are often applied in situations where the fiber content is low, the ash content is high, or

the solids are otherwise difficult or impossible to dewater on a coil filter.

**10** If adequate quantities of primary solids are available for admixing, secondary solids are usually dewatered as combined sludges.

**11** Combined sludges with as high as 30 percent biological solids are being dewatered on vacuum filters, centrifuges and V-presses at conditioning requirements of 2 to 7 pounds polymer ton. Machine capacities can be expected to be lower in combined sludge dewatering than primary sludge dewatering.

**12** High cake consistencies and the necessity for handling difficult-to-dewater sludges have prompted recent interest in plate and frame pressure filtration. Industry pilot investigations suggest that combined sludge cake consistencies of 30 to 45 percent and secondary sludge cakes of 30 to 40 percent may be anticipated with a variety of conditioning techniques. The relative merits of high and low pressure operation and precoat utilizaiton, and comparison of anticipated and actual performance remain unresolved. Performance in full scale installation will warrant continued industry attention.

**13** Moving belt presses and recent generation centrifuges offer new alaternatives for sludge dewatering, especially in hydrous sludge applications.

**14** The pulp and paper industry disposes of most of its waste treatment solids on the land, incineration being a common alternative with sludges of less than 10 percent ash content. Definition of potential for wider application of sludge incineration requires further investigation.

Most recently the P. H. Glatfelter mill at Spring Grove, Pa. (26) reported successful startup and operation of a twin belt press for dewatering primary sludge. Clarifier underflow is first thickened to 4-6 percent solids in a 60 ft (18m) gravity thickener before pressing to 35-40 percent solids at a rate of 50-60 tpd on the 80 in (200 cm) width press which is operated intermittently depending on the amount of sludge needing to be dewatered. Uses and applications for the dewatered sludge, which is presently disposed of on land, are being investigated.

## Special Physico-Mechanical Approaches to the Dewatering of Waste Activated Sludges

As noted above, some success has been achieved in dewatering mixtures of primary and secondary sludge without chemical coagulant addition where the long fibred sludge content is adequate to overcome the difficulties introduced by hydrous activated sludge. Where the long fibre content in inadequate, several remedial approaches have been employed or considered. Those that can be categorized as physico-mechanical treatment include (a) thermal conditioning of sludges, (b) specialized dewatering of the segregated activated sludge or other hydrous sludges, and (c) addition of waste bark as a filtration aid for conventional filtration. Developments in these areas are reviewed below.

1 *Thermal Conditionong of Hydrous Sludges* - A recent National Council study (27) has explored this subject in depth. Study findings can be summaried as follows:

**a** Hydrous groundwood fines and waste activated sludges associated with the treatment of wastewaters from pulp and paper manufacturing, inclusive of sludges resulting from chemical treatment of biologically treated effluents, were all demonstrated to be highly responsive to thermal conditioning. That was not the case for alum based water treatment sludge. For waste activated sludge, acid-assisted oxidative conditioning offered only a very slight, if any, advantage beyond that achieved with only a non-oxygen limiting envornment.

**b** Improvement in sludge filterability is related to the solubilization of sludge volatile constituents up to some optimum solubilization level between 40 and 50 percent. Beyond that degree of solubilization, a capability limited to oxidative conditioning, solids dewaterability exhibited a classical reversion.

**c** Oxidative conditioning in a non-oxygen limiting environment poses no distinct conditioning advantage over non-oxidative processes. In fact, in the case of alum-coagulated biological solids, filter leaf tests confirmed results with conventional filtration parameters showing that oxidative conditioning was less effective than conditioning in the absence of oxygen. However, the presence of oxygen accelerates the rate and extent of volatile solids solubilization.

**d** Regardless of the mode of conditioning or acid addition, solubilization of activated sludge volatile constituents resulted in an associated supernatant COD increase equivalent to approximately 50 percent of the mass of volatile solids hydrolyzed. The corresponding ratio for the alum-coagulated solids was less, suggesting the possible importance of aeration system sludge age to the character of the supernatant. The ratio of filtrate BOD to COD for groundwood fines and waste activated sludge including when acidified was 0.5 to 0.6 in comparison to 0.3 for the solids separated with chemical coagulation of biologically treated effluents.

**e** Heat treatment represents a viable means of conditioning the most difficult of sludges. Though not within the scope of this study, technical personnel at installations contemplating its use should be aware of experience cited within the literature outlining its implications for significantly increased raw waste and color load and (b) such reported operational problems as corrosion, scale, plugging and equipment maintenance.

2 *Specialized dewatering of waste activated sludge* - The National Council recently completed a pilot-scale evaluation of seven alternative dewatering approaches for waste activated sludge (28). These included (a) pressure filtration, (b) precoat vacuum filtration, (c) Tail-Andritz filter belt press, (d) Permutit dual cell gravity-multiple press roll filter,

(e) capillary suction sludge dewatering. (f) Sharples horizontal bowl decanter centrifugation and (g) ultra-filtration. The test sludge was that generated in an integrated bleached kraft pulp and paper mill activated sludge treatment system. Results of the study were summarized as follows:

**a** All of the units investigated were capable of dewatering waste activated sludge. Chemical conditioning, however, was mandatory in all cases except for centrifugation and ultrafiltration.

**b** The pressure filter and precoat vacuum filter generated the driest cakes (25 to 40 percent solids) making them likely alternatives where incineration, or dry cake for landfilling or hauling are involved in final disposal. The possible effects of handling and disposing of the nonsludge fraction of these cakes require consideration.

**c** Pressure filter performance on this sludge was not enhanced by higher operating pressures (13 atmospheres vs. 7 atmospheres). Additional industry experience suggests lower operating pressures to be adequate for other types of sludges as well.

**d** The filter belt presses generated cake consistencies approaching 20 percent solids. Relatively low power and maintenance costs are likely to be associated with these units. The filter belt presses generated the driest cakes of the units not utilizing inorganic conditioning, suggesting them as a likely alternative where inorganic contamination of the sludge is not desired.

**e** The gravity filter and centrifuge generated cakes at 8 to 10 percent maximum consistency, indicating probably applications in prethickening for pressure filtration, digestion or heat treatment, or where land disposal of semi-fluid sludge is envisioned. The gravity filter offers very low power costs while the centrifuge offers no sludge conditioning costs.

**f** The ultrafilter was capable of thickening sludge to 7 percent consistency. However, the high power costs associated with overcoming the pressure drop through the system suggest that a different membrane configuration would be required to make the process feasible.

**g** There were several units that consistently operated at solids recoveries of 99 percent or better suggesting their applicability where the liquid fraction solids levels had to be low. These units were the pressure filter, the precoat vacuum filter, the gravity filter and the ultrafilter.

**h** Artificially increasing the specific resistance of the unconditioned sludge from a range of 50 to 200 x $10^7$ sec$^2$/gm to a range of 150 to 400 x $10^7$ sec$^2$/gm had a substantial detrimental impact on the performance of those units which handled the sludge. Caution is, therefore, indicated in applying the data in this study directly to other sludges particularly where knowledge of the specific resistance of the sludge in question is lacking.

**i** Most of the units indicated a sensitivity to feed concentration, and achieved or indicated significantly superior performance at sludge feed consistencies of 2 percent solids as compared to 1 percent solids.

**j** Additional pulp and paper industry experience has shown both pressure filtration and filter belt pressing to be applicable to primary, secondary, and combined sludge dewatering. Performance levels are determined by the equipment configuration, the nature of the solids, the type and amoung of sludge conditioning, and the feed consistency.

**k** Some mills have encountered substantial startup difficulties with pressure filters including plate breakage, media tearing, and poor sludge distribution in the chambers. These problems have generally been overcome, some, however only with intense effort.

**3** *Use of waste bark as a filtration additive* - Waste bark is normally available at all integrated pulp and papermills except where the wood supply is derived from sawmill chips. Encouraged by success reported by Bishop (29) at a bleached kraft newsprint mill, the National Council's continuing research program pertinent to the dewatering and disposal of hydrous sludges was extended to bark conditioning of biological sludges. Variables investigated included bark type, particle size, size distribution, and addition level. Factors of significance to filtration established on the basis of filtration theory and empirical studies cited in the literature were reviewed and observed to apply to bark-conditioned slurries (30).

An optimum bark particle size in the range of 20 to 40 mesh was suggested at minimum addition levels of 3-parts bark to 1-part secondary sludge. Solids retentions greater than 85 percent were attained only where particle sizes of less than 40 mesh constituted at least 10 percent of the bark supplement. Associated sludge solids loading rates were less than 2 lbs/sf/hr. Nevertheless, application of bark for the conditioning of secondary sludges will require further study to evaluate bark size reduction processes and assess the conditioning properties of resulting size distributions.

Based on the results in this investigation, the following conclusions were reached:

**1** Successful use of bark in the size range greater than 8 mesh for conditioning of combined primary-secondary sludges cannot be achieved without the presence of fibre in the sludge.

**2** Optimum conditioning of biological sludges requires size range selection of bark in the 20 to 40 mesh range. Resulting net solids loading rates increase linearly with bark addition.

**3** Solids retention on the filter medium exceeding 85 percent is attained only where the bark size distribution is such that at least 10 percent passes a 40-mesh sieve. Associated net solids loading rates range from 1 to 2 lbs/sf/hr, with the major values occurring with more uniform particle size distributions.

**4** Solids retention increases as the uniformity of particle sizes constituting the bark supplement is decreased.

**5** Cake handling properties require a minimum addition of three parts bark to one part secondary sludge.

**6** Within the scope of this study, hardwood bark is unsuitable for the conditioning of biological sludges, and exerts a detrimental effect on the superior softwood bark where the two are combined.

**Separation of High Ash Component from High Ash Fine Papermill Sludges**

The manufacture of filled and coated grades of paper frequently gives rise to sludges rich in ash components such as clay and $TiO^2$. Their high ash content (a) can have a negative bearing on their subsequent disposal, particularly by incineration, and (b) raises the possibility of their subsequent processing for recovery and reuse of the ash components, and to facilitate disposal of the low-ash component. A study of this possibility was recently completed by the National Council.

The summary report (31) presents the results of (a) semi-pilot plant scale study of several means for separating the ash component from the fibrous organic portion of the papermill primary sludge, and (b) pilot plant paper machine trials of reuse of this material as either filler or coating pigment for filled and coated paper grades. The recovery methods studied were screen-separation and wet oxidation, and were selected for more detailed examination in a previous laboratory investigation of a larger number of alternatives. The possibility of brightening such screen-recovered material using several bleaching sequences was also explored.

Results of the study offer considerable encouragement regarding the use of screen separation to produce reusable filler material. While some reduction in sheet brightness was noted, the possibility of remedying this drawback by oxidative bleaching appears encouraging. Wet oxidation was also found capable of producing reusable filler material, and with lesser adverse effects on product brightness. Preliminary evaluation indicated, however, that its potential for producing reusable coating material is not too promising.

The findings open up a number of possibilities for mill-specific consideration of such processes for recovery and processing of the high ash component and its subsequent reuse. They also identify a number of areas for further study that should expand the technological process economics base for this sludge disposal/materials recovery approach and identify the limits for its practical, continuous application at individual mills.

A recent application of these laboratory and mill-scale trial results is reported by Flynn (32) for the recovery of filler clay and pigment from paper mill sludge by wet air oxidation. The mill employs two-stage activated sludge for effluent treatment and all sludge was lagooned. Because conventional high temperature incineration of the sludge increased abrasive characteristics of the filler, wet air oxidation was chosen in order to recover the filler in a reusable form. The process was described in which the sludge at 8 percent solids is reacted at 2500 psig and 600° F (17.24 MN/m², 315°C) for 90 percent destruction of organic material.

## Summary - Developmental Trends and Possible Areas for Cooperative Study

As noted earlier in our paper on physico-chemical treatment, the grouping of treatment methods under the heading of 'physico-mechanical' covers a multiplicity of approaches, objectives, technologies and practical possibilities. In some respects the approaches represent a more elementary level of treatment, to the degree that they are unaided by chemical addition. In other respects, however, they can be viewed as representing an attempt toward economic optimization of processes so as to avoid the use of chemicals and substitute additional power use or equipment cost to achieve that goal.

The developmental trends evident can be summarized as follows:

**1** It is likely that total mill effluent clarification at the primary level will continue to be characterized by physico-mechanical since the necessity of unusually high clarity is not critical at this point. One notable exception is evident with regard to lime decolorization which in a number of instances will be combined with primary sedimentation.

**2** At the secondary clarification level, more frequent use of coagulant aids is anticipated both to meet agreed on water quality protection objectives as well as the frequently arbitrarily restrictive effluent limitations stemming from governmental effluent limitations guidelines. Similarly, flotation and mechanical screening options will receive greater attention in efforts to exceed the present capability of gravity sedimentation clarification.

**3** Concerted efforts to reduce mill effluent flow through greater internal water reuse will lead to more extensive screening of white water streams to aid in closure of white water systems.

**4** Stripping of condensates from chemical pulp mill liquor evaporation and heat recovery systems will become more extensive as part of an optimization approach to unifying internal and external control measures.

**5** Modest beginnings have been made in the area of activated carbon renovation of paper mill white water for reuse. It remains to be seen how extensive this practice will become in contrast to screening, filtration and gravity separation of fines from white water.

**6** Sludge dewatering and clarfication will continue to represent a major area of study and application of physico-mechanical treatment approaches.

Some areas that suggest themselves for

possible cooperative study include the following:

1 Determination of water quality needs for both pulp and paper manufacture as a guide to development of specific effluent treatment objectives, particularly for in-process effluent streams which are candidates for further reuse.

2 Examination of the economic and treatment optimization aspects of varying degrees of condensate stripping, stressing the most economic level of use and source of stripping steam and the incremental savings achieved in use of existing biotreatment systems, or their possible future avoidance or minimization for a new generation of more highly closed pulp mills.

3 Evaluation of new sludge dewatering and conditioning approaches for sludges rich in hydrous components or from which long-fibred material has been deliberately separated. Coupled with this work should be a common examination of the possibilities for segregation of high ash material for industrial reuse.

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# Employment of Microstrainers in the Waste Water Treatment Practice

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At present microstrainers are mainly used in water supply for plankton removal from natural water. They alleviate the sand filters operation and allow to increase their output.

However, microstrainers can also be used for waste water treatment. They can serve as possible substitutes for primary clarifiers in the technological scheme of treatment. The experience has shown that microstrainers ensure final treatment of effluents after secondary settling tanks.

Microstraining is very promising because microstrainers are compact and economical, simple in operation and permit the process to be automated.

In the Soviet Union a number of scientific researches were carried out evaluating the efficiency of the microstraining process in application to concrete conditions.

The gained experience allows them to make some general conclusions concerning the methods of experiment and the ability of expansion of microstrainer's field of application.

The characteristic feature of microstraining as the method of waste water treatment from suspended solids consists in the fact, that a very thin layer formed by SS particles retained on the screen with mesh sizes of 40-90 microns.

In the Soviet Union as well as abroad drum microstrainers are preferably used. (Fig. 1)

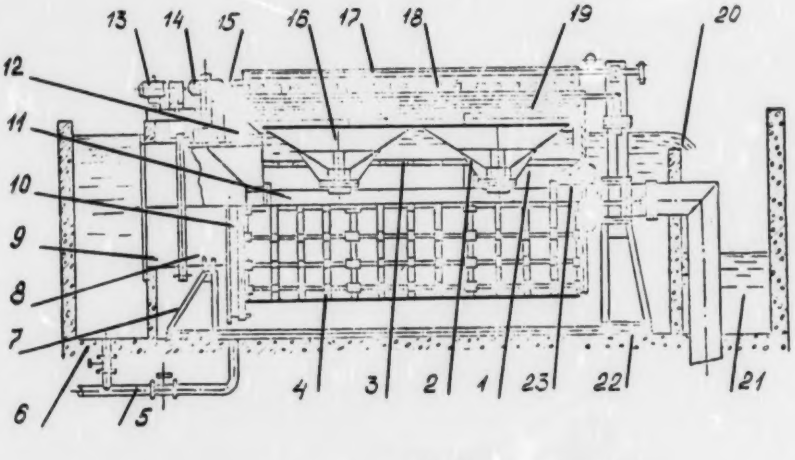


**Figure 1.**
**Scheme of a screen drum filter:**

1. Drum
2. Transverse frames
3. Stringers
4. Rigid ribs
5. Drain pipes
6. Influent channel
7. Front frame
8. Inlet pipe
9. Cast-in fitting pipe
10. Pin wheel
11. Wash water draw-off pipe
12. Front bearing
13. Electric motor
14. Reducer
15. Gear
16. Bunker
17. Wash water feed pipe
18. Sprinkler
19. Bactericidal lamps
20. Weir
21. Filtrate channel
22. Back frame
23. Back bearing.

Microstraining is carried on at continuous rotation and regeneration of the screen. Microstraining efficiency depends on a number of factors and, in the first place, on the formation of a thin sludge bed on the inner surface of the microscreen. Formed filtering sludge bed is thickening negligibly and can be easily washed off by washing water. So the control of washing speed is of great importance for creation of optimum conditions under which the sludge layer is formed and for ensuring high efficiency of waste water treatment. Washing water flow should be regulated in such a manner as to preserve a required sludge layer on the screen after washing and to maintain the head loss within the certain limits.

Optimum parameters of microstraining defy theoretical calculation and are usually defined experimentally.

Great variety of types and compositions of industrial wastes demand special tests to be carried out on wastes of each branch of industry and sometimes on wastes of each enterprise. The need for the large number of tests to be carried out and labour-consuming character of these tests caused the development of a simple method of modelling for tentative evaluation of main relationships, permitting to give an approximate characteristics of microstraining under concrete conditions.

A filtering column is used for this purpose. In the lower part of the column there is fixed filtering screen. Despite the fact that filtering is carried on in static conditions, this method of modelling allows to objectively evaluate the ability of microstraining employment for given conditions. The influence of such factors as the type and the mesh size of the micro-screen, the losses of head, filtering velocities on the efficiency of treatment is determined at the first approximation.

After preliminary investigations in static conditions, the main operation factors may be corrected at pilot plants.

It should be noted, however, that existing models of drum microfilters ensure only tentative study of microfiltering, as the investigation of back washing of the micro-screen which in many respects determines the structure of filtering sludge bed, is impossible. Non-observation of adequate speeds of the screen rotation under the nozzle of the washing device in the model and in the full-scale installation is among the serious shortcomings of the known technique of modelling. When modelling the working parameters of the model one should proceed from the equality of the back wash duration at equal periods of rotation.

In the laboratory-scale model of the microstrainer, developed at VODGEO Institute, full-scale velocities of the screen rotation were ensured by a special mechanism, speeding up the screen movement when it moved under washing jet. (Fig. 2)

The results of investigations carried out on the laboratory model were verified at pilot plant.

A pilot microstrainer is a cylindrical screen drum of 300 mm in diameter and 200 mm length, located in metal reservoir. It rotates with the help of electric motor. The number of revolutions of the drum is changing step by step within the range from 5 to 20 rev/min.

The drum was equipped by the brass screens, two of which are supporting. The working screen is located between the supporting ones. The mesh size of the working screen ranged from 40 to 90 microns. The mesh size of supporting screens percepting the loads formed by the pressure overfall during filtering and washing was equal to 1.25 mm. The filtering sludge bed and required overfall of the pressure on the screen were maintained by adjacement of the wash water flow and speed.

Washing of the screen was carried on with the help of the travelling nozzle situated under the drum and moving along the generating line of the drum. The employment of such a way of screen washing brought the washing conditions to the full-scale operation conditions.

The following parameters of the process were registered during investigation: duration of the filtering cycle, the rate of filtering, waste water treatment efficiency.

On the basis of the investigations there were determined relationships between the efficiency of the microstraining and the filtering rate, initial concentration of suspended solids in the influent and the number of the drum revolutions.

In order to choose the optimum parameters of the process, obtained relationships are developed quickly to be presented in the form of summary graph, where the treatment efficiency is represented as a function of the filtering rate and drum rotation rate (Fig 3, 4)

Such parameters as the head on the screen, the mesh size, and wash-water flow are changed within a narrow range and were equal respectively:

- head losses 150-200 mm of water column;
- wash-water flow 6% (for raw waste) and 3% (for the effluent after secondary treatment).

On the basis of the data given in the summary graphs the following parameters of microstraining may be recommended.

For clarification of raw waste (instead of primary clarifiers) at initial concentration of suspended solids 150-200 mg/l.

- clarification efficiency - 45%
- filtering rate - 30 m/hour
- filtering cycle - 9 sec.
- mesh size of the screen - 90 microns

For final waste water treatment (after secondary settling tanks) at initial concentration of suspended solids 25-60 mg/l.

- clarification efficiency - 65%
- filtering rate - 45 m/hour
- filtering cycle - 6-8 sec.
- mesh size of screen - 40 microns.

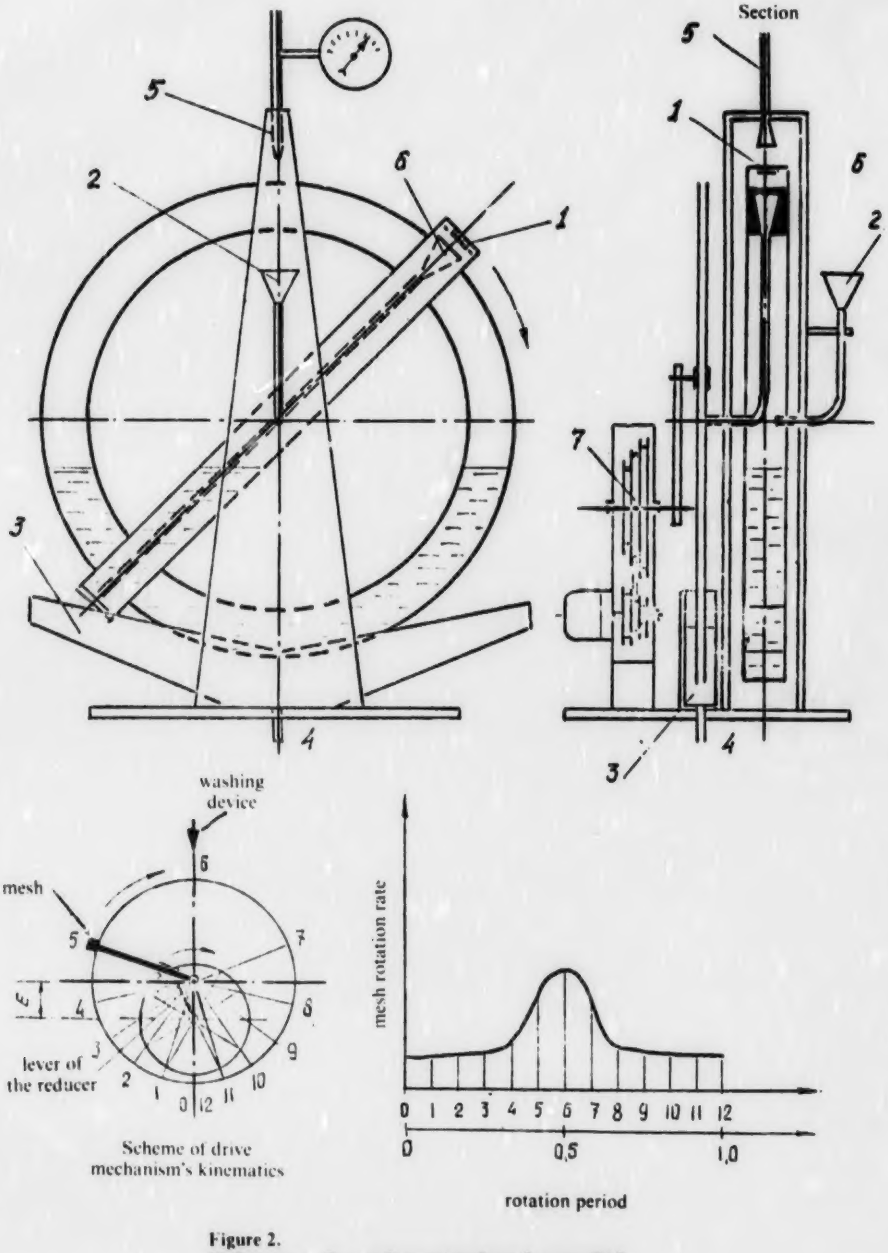

Section
5
1
6
2
5
2
6
1
3
4
7
3
4
washing device
mesh
lever of the reducer
Scheme of drive mechanism's kinematics
mesh rotation rate
0 1 2 3 4 5 6 7 8 9 10 11 12
0
0,5
1,0
rotation period

**Figure 2.**

**Scheme of a microstrainer's model**

1. A cell with a micromesh
2. Feeding of influent
3. Wash-water collection trough
4. Wash water drain
5. Washing jet
6. Wash-water receiving funnel
7. Micromesh drive reducer.

Figure 3.

Dependence of the process efficiency on the filtering rate, initial concentration of suspended solids, revolutions of the drum per minute (after primary treatment).

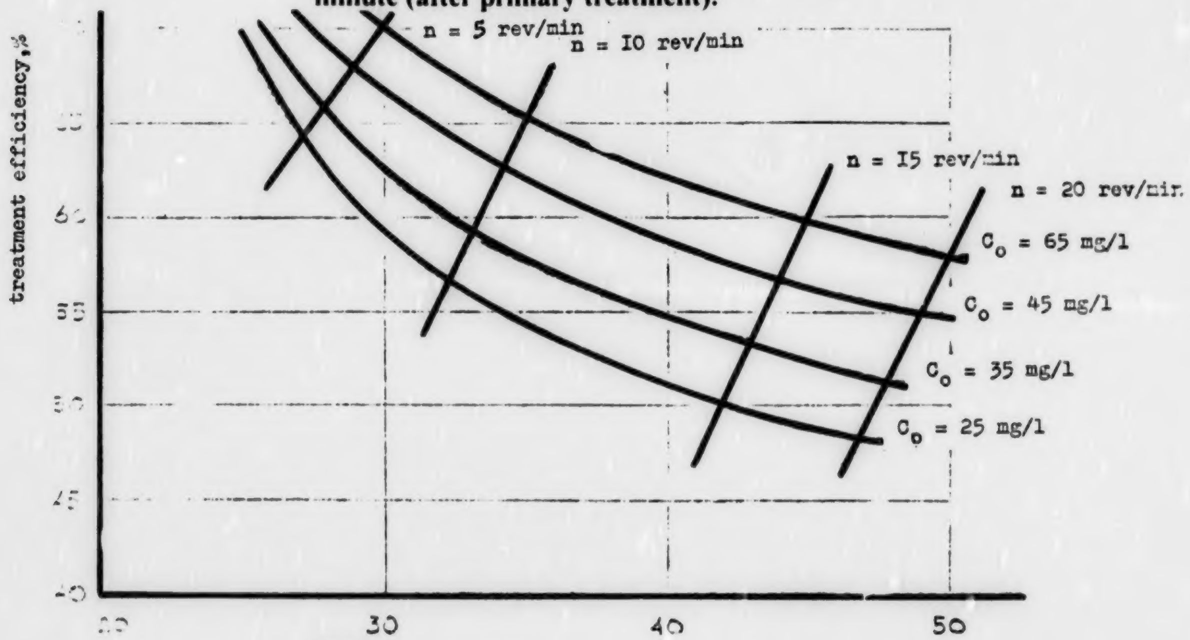
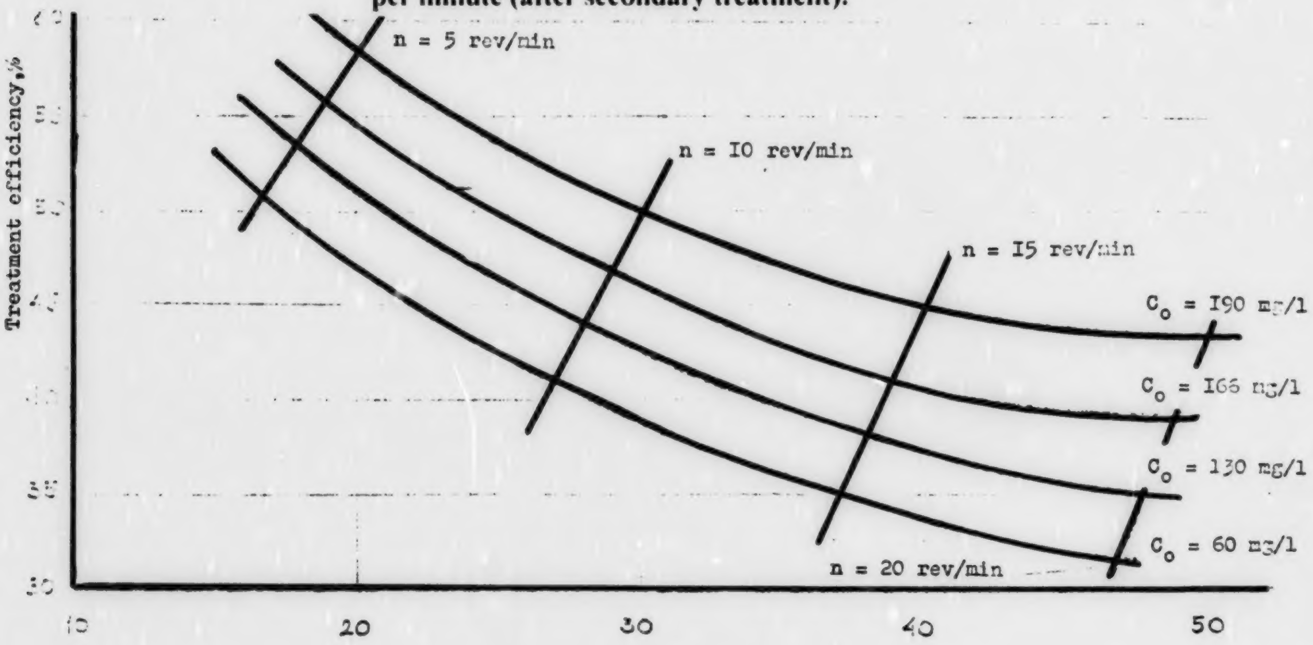


Figure 4.

Dependence of the process efficiency on filtering rate, initial concentration of suspended solids and revolutions of the drum per minute (after secondary treatment).



In case of preliminary treatment $BOD_5$ removal up to 25% was observed. After filtering of biologically treated water $BOD_5$ removal was up to 40%.

Parameters taken from summary graphs can be used for approximate design of microstrainers operating under similar conditions. More general dependences may be obtained on the basis of theoretical premises and generalization of experimental data known.

The microstraining process can be described with the help of semi-empirical dependences based on the following assumptions:

1 a sublayer of certain mean thickness "$M_0$" is formed on the rotation drum microstrainer.

Thickness of this sublayer depends on the initial suspension flow, the time of filtering and the difference between the initial and resulting concentration of suspended solids:

$$M_0 = \frac{(C_0 - C_1)\,T\,W}{\gamma}, \text{ mm}$$

where: $M_0$ = thickness of the sublayer, mm;
$C_0$ — initial concentration of suspended solids, mg/l;
$C_1$ — resulting concentration of suspended solids, mg/l;
T — filtering cycle, sec.;
W — filtering rate, cm/sec;
$\gamma$ — specific weight of particles, forming the sludge bed, g/cm³, $\gamma = 0.8 - 1$ g/cm³.

2 The sublayer can be described as the additional filtering sludge bed with orifice diameter "$d_0$", which is equal to the minimum diameter of detained particles.

Diameter of the particles forming the sublayer can be determined by the Stokes equation:

$$U_0 = \frac{g d_0^2}{18\eta}(\rho^1 - \rho^2), \text{ cm/sec,}$$

where $U_0$ — the rate of the particles sedimentation, cm/sec;
$d_0$ — particle diameter, cm;
$\eta$ — water viscosity, $\eta = 0.01$ g/cm/sec;
$\rho^1$ — specific weight of particles, g/cm³;

$$\rho^1 = 1.6 \text{ g/cm}^3;$$

$\rho^2$ — specific weight of water, g/cm³;

$$\rho^2 = 1 \text{ g/cm}^3.$$

3 Relationships between the head loss and the flow in the sublayer resembling a very thin gauze can be described by well-known hydraulic formulae for outflow through submerged orifice.

On the basis of experimental data obtained for microstraining and sedimentation of suspended solids, the following formula can be used for practical calculations:

$$W = \left(\frac{\Delta H}{7.24}\right)$$

0.33 — 10 $U_0$, cm/sec

Besides filtering rate, relationships between filtering cycle and the given efficiency of suspended solids, capture and construct dimensions of the filter and determine the microstrainer's design:

$$T = f(Q, C_0, C_1, D, n)$$

The relationship between the filtering cycle duration and the filter dimensions is determined by the following ratio:

$$T = \frac{S}{V}, \text{ sec.}$$

where S - the length of the submerged part of the drum perimeter, m.;
V - linear rotation speed of the drum generating, m/sec.

The efficiency of microstraining is characterized by the specific load expressed by the amount of pollutants detained by one working unit of microscreen area versus unit of time.

$$G = \frac{Q}{F}(C_0 - C_1), \quad \text{kg/m}^2\text{/hour}$$

The dependence of the filtering cycle on the specific load is described by the empiric equation:

$$T = 0.0017\ G^{-1.93}, \text{ sec.}$$

The technical-economic evaluation of the microstrainers' employment has revealed their considerable advantages over standard schemes of treatment. Technical-economic evaluation was carried on for pre-treatment and final treatment of biologically treated effluents. Both schemes were evaluated at the treatment capacities of plants equal to 50,000; 100,000 and 200,000 m³/day. Two variants were compared in each scheme.

In the first variant waste waters were pre-treated on screens, sand traps, in primary clarifiers, aeration tanks, secondary settling tanks with chlorination before discharge into receiving waters.

In the secondary variant primary clarifiers were replaced by microstrainers in order to reduce capital expenditures. The other treatment plants remained unchangeable.

The use of microstrainers instead of primary clarifiers at treatment plants with output 50,000, 100,000 and 200,000 m³/day gives the possibility to reduce capital expenditures by 75-90%.

For final treatment of effluents treated in the secondary settling tanks the following two alternatives were compared:

I - final treatment of the secondary settling tank effluent in biological ponds;
II - tertiary treatment of the secondary settling tanks effluent on microstrainers followed by final treatment in biological ponds.

Employment of microstrainers for final treatment of biologically treated effluents permits the area of biological ponds to be half reduced. In its turn this reduces capital expenditures for treatment plants with output of 50,000-200,000m³/day by 40-60%.

## Conclusions

1. Microstraining has been employed recently both as an independent method of waste water treatment and as a part of technological scheme at different waste water treatment plants.

**2.** Observation of full-scale conditions of washing is necessary when modelling microstrainers. The equipment developed gives us the possibility to determine the main parameters of microstrainer operation and the screen regeneration in laboratory and full-scale conditions.

**3.** Microstraining provides $BOD_5$ removal up to 25-30% and suspended solids removal by 45% (after pre-treatment) and suspended solids removal by 50-60% and 30-40% removal of $BOD_5$ (for final treatment).

**4.** Analysis of the physical nature of microstraining has shown that the process can be described with regard for granulometric composition of suspended solids (SS).

**5.** Technical-economic calculations have shown that microstrainers' employment is profitable in case of pre-treatment of waste water (instead of primary clarifiers). Capital expenditures are reduced by 70-90%.

Employment of microstrainers for final treatment of biologically treated effluents twice reduces the are of biological ponds. ponds.

**6.** Microstraining is widely used for final treatment of biologically treated effluents of articifical fiber plants, pulp and paper complexes, chemical enterprises and municipal sewages. In case of pretreatment the use of microstraining is limited. It finds application mainly for pulp and paper and chemical effluents' pretreatment.

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# The Control of Refinery Mechanical Waste Water Treatment Processes by Controlling The Zeta Potential

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## Abstract

Granular media filtration and dissolved air flotation play a key role in optimizing a water management program for refineries. Proper utilization of these processes can achieve major capital and energy savings as well as provide for enhanced performance of biological treatment systems.

An intrinsic property of solids in the presence of water is an electrical surface charge. Maximizing the efficiency of filtration and dissolved air flotation processes require that these coulombic repulsive forces be controlled by controlling the physicochemical properties of the dispersed solids. Of the four theoretical colloid destabilization mechanisms, charge neutralization and bridging are the key mechanisms to optimize these unit operations whereas colloid entrapment and double layer repression are less attractive.

Zeta potential titration curves are used to quantify proper destabilization chemical treatment, compare the effectiveness of chemicals, and measure synergisms and antagonisms of various components in the waste stream, thereby determining the most cost effective chemical treatment.

Hydraulic loading limitations of granular media filters relate chiefly to 1) the nature of the destabilized colloidal aggregates, and 2) water temperature during filtration. Biocolloids and coke fines represent extremes of the former, and the latter limitation is viscosity related, which contributes to dispersion forces on the captured aggregates.

For air flotation, the design of the recycle air system and the surface loading of the flotation zone are the critical design elements.

## Introduction

Granular media filtration and/or dissolved air flotation (DAF) units play a key role in optimizing a water management program for refineries. Proper utilization of these process elements can achieve major capital and energy savings as well as provide for enhanced performance of biological treatment systems.

An intrinsic property of solids in the presence of water is an electrical surface charge. When colloids are being considered, the electrical charge is called zeta potential (ZP). Almost all matter dispersed in spent process water such as oil particles, silt, biocolloids, inorganic colloids, etc., has a negative ZP and is repelled by the negative electrical surface charge of the granular media as flotation bubbles. Mother Nature is always "left-handed" and you *must* control Mother Nature if granular media filtration and DAF are to achieve maximum solids removal effectiveness. Maximizing solids removal efficiency requires that these coulombic repulsive forces be controlled by controlling the physicochemical properties of the dispersed solids.

This article will:

1 Define and describe what is meant by granular media filtrations and dissolved air flotation (DAF);

2 Discuss briefly filtration and flotation mechanisms;

3 Cite refinery examples where application of granular media filtration and DAF make a major savings possible in an overall water management program;

**4** Describe and discuss the a) electrical properties of waterborne suspended matter, b) colloid destabilization mechanisms, and c) the chemical properties of destabilization chemicals used to control these electrical properties;

**5** Describe the approach to determining optimal chemical treatment preparatory to filtration and dissolved air flotation; and

**6** Present typical chemical pretreatment and hydraulic guidelines for various refinery filtration and dissolved air flotation applications.

## Granular media filtration

Granular media filtration may be defined as *clarification of a suspension* of dispersed material by passage through a bed of porous media that separates, and retains within the media, the solids constituting the suspension.

Granular media filtration in the petroleum industry usually means "direct filtration." Direct filtration involves injection of required chemicals into the water and immediate transfer of the treated water to the filter, i.e., there are no flash mix, flocculation, or clarification process steps prior to filtration.

The normal operation of granular filters involves downward flow through the media until pressure drops due to clogging, or breakthrough of suspended matter, increases to a predetermined limit. The filter is then cleaned by reversed flow fluidization after pretreatment by air scrubbing or a hydraulic surface wash.

Filter media include beds composed of sand; sand and coal; sand, coal and garnet; and other minerals and synthetic materials. For best results, the suspension being filtered should pass through a bed of increasingly smaller pore size.

A more recently developed bed comprising four media that achieves this objective is shown in Figure 1 (1).

Granular media filters are frequently referred to as gravity or pressure filters. Since granular media filters are only a small part of the spectrum in filtration art, the meaning associated with these descriptions may be at variance with other filter technology. In the simplest terms, a gravity filter is a downflow design in which the water standing above the filter media is under atmospheric pressure. A gravity unit may be operated as a constant or declining rate unit, i.e., as the filter media clogs and the pressure drop increases, the rate may be maintained by increasing the head of water above the media, or allowed to decrease by maintaining a constant head. The pressure drop across a freshly regenerated unit is about 1 foot of water and the pressure drop at the end of the filter cycle may be as little as 5 feet or as much as 10-12 feet of water. A pressure filter of the granular media type is simply the same system in an enclosed vessel; i.e., the operating pressure drops across the media are about the same. In contrast, pressure filters in filtration systems other than the granular media type may have pressure drops orders of magnitude higher. Within the framework of these descriptions it is obvious that a variety of engineering and hydraulic designs are possible. Historically, granular media filtration was viewed as a polishing step following a clarifier. More recently, direct filtration of highly contaminated waters has been widely demonstrated, with large savings in capital, chemical, and sludge treating costs.

## Filtration Mechanisms

Mechanisms for retention of solids within the pores of granular media are separated into two principal processes: a transport step and an attachment step. The transport step involves movement of the dispersed phase material to the vicinity of the granular media surface and the attachment step involves attachment of the particles on the media surface. The transport mechanisms may involve diffusion, interception, sedimentation and hydrodynamic actions. The attachment mechanisms may involve van der Waal forces, electrical double layer interaction, mutual absorption or hydrogen bonding (2).

Experimental comparisons of the filtration of colloidal ferric hydroxide suspensions with the filtration of well-flocculated suspensions of ferric hydroxide, both performed under identical conditions of filtration, demonstrate a much higher filtration efficiency for the floc. Studies (3) have shown that removal of *colloidal* suspension by filtration appears to be possible only when the colloidal particles to be filtered carry an electrokinetic charge opposite to the charge of the filter media used. The removal of the colloid is by electrokinetic sorption of the colloidal particles on the surface of the filter media. This kind of "filtration" phenomena has limited application to the filtration of industrial waste water because of complications encountered in application, the complexity of which are beyond the scope of this article.

## Dissolved Air Flotation

Dissolved air flotation (DAF) may be defined as clarification of a suspension of flocculated material by contact with minute bubbles that attach to the solids constituting the suspension, causing the air solids mass to be buoyed to the surface leaving a clarified water.

This definition puts proper emphasis on the requirement that the material being separated should not be colloidal, with the inherent high negative zeta potential required to maintain the colloidal state, but a flocculated suspension. A flocculated suspension implies a proper chemical pretreatment consistent with the needs of the colloidal system. A flocculated suspension requirement also determines the design basis of the DAF unit; it shall have provisions for mixing chemicals, flocculating the destabilized suspension, a flotation zone for phase separation, and shall be the recycle air pressurization design. The seven near boxes in the API separator shown in Figure 2 were converted to a DAF unit. A profile view is shown in Figures 3 and 4.

Figure 5 illustrates a critical design problem. The *vena contracta* of the pressure reducing valve creates a very strong vacuum and will cause the dissolved air to disengage as very large air bubbles unsuitable for air flotation if the valve is more than about 1 meter from the distribution header. To keep the pressure reducing valve out of the water, orifice plates in the distribution header are used to provide the required back pressure.

With a properly designed recycle air pressurization system, when the pressure is reduced the dissolved air separates as finely divided bubbles ranging in size from 30 to 120 microns with most of them in the 60 - 100 micron range and ready for attachment to the dispersed solids. According to Vrablik (13) the air can become attached three different ways:

1. By adhesion of an air bubble to a particle either by collision or as condensation sites as the air precipitates out of solution.

2. By entrapment of the air bubble in the irregularities of flocculated particles.

3. By adsorption of the air bubble in the floc structure as the floc is formed.

Provided the particles are adequately destabilized, and the flotation zone is relatively free from turbulence, the particles tend to behave in accordance with Stokes' equation:

$$V_t = \frac{g\,(dw - da)\,D^2}{18\,u} \qquad \text{(Equa. 1)}$$

$V_t$ = terminal velocity of air-solid agglomerate
dw = density of water
da = density of air-solids agglomerate
D = diameter of air-solids agglomerate
u = viscosity of water
g = gravity constant

For the air flotation process to work, the value of the term (dw-da) must be greater than zero. The rate of rise varies directly with the square of the diameter of the air-solid agglomerate and inversely with its density. Density can be changed only by making more flotation air adhere to the particles. Diameter can be easily increased by substantial amounts by means of chemical coagulation and flocculation. In addition, the flocculated particles will trap and retain more air than individual particles.

The key to optimizing the efficiency of filtration and DAF operations, therefore, is to recognize that essentially all colloidal systems encountered in nature have a negative electrical surface charge. Considering that, in the case of filtration, granular media (coal, sand, garnet, etc.) and in the case of DAF, the flotation bubbles, have a negative electrical surface charge also, it is not unexpected that colloidal solids rapidly break through granular media due to repulsion of like charges when not properly chemically pretreated, or have a poor capture efficiency in the case of DAF. The optimal application of these processes to waters relates primarily to recognizing and responding to the required water chemistry for destabilizing the colloidal material into agglomerates tough enough to resist redispersive hydraulic forces.

## Refinery Examples Where Application of Granular Media Filtration and DAF Results in Major Savings

The elements of inplant and end-of-pipe treatment which must be addressed at each refinery are outlined in the "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Petroleum Refining Point Source Category." The objectives and some process options for each of these elements are outlined in Figure 6. Filtration is used for intake water clarification, and the filtration of primary and secondary effluents in the end-of-pipe treatment sequence. DAF treatment of primary effluents is an option.

### Filtration or DAF Treatment of API Separator Effluents Results in ASU Savings

The filtration or DAF of primary effluents can have a major impact on the purification effectiveness of secondary treatment, and the amount and characteristics of waste activated sludge produced. As in municipal wastes, a refinery's raw waste load (RWL is defined as contaminants in primary effluent) BOD/COD is characterized as being about 50% soluble and 50% insoluble, *on the average*. But the NPDES Permit program requirements are restrictive enough that the designer of process units must use about a 98% probability basis for RWL; and here is where the use of filtration or DAF results in a major capital and operating savings.

The impact of granular media filtration or DAF on the design of a following activated sludge unit (ASU) can be visualized by making probability plots of refinery RWL data (Figures 7, 8, and 9). In large and complex refineries the oil and grease in the raw waste load can vary over a year's time as shown in Figure 7. Whereas the 50% probability (median) is only 70 mg/l oil, about 5% of the data may be in the 600+ mg/l range due to causes previously outlined. Optimized ASU operation at very high sludge ages has been achieved with excellent sludge properties when all discontinuous phase oil and solids are removed. When intermediate treatment includes chemical destabilization and filtration, results for oil and grease as shown in Figure 7 can be achieved.

Removing oil from the process water effluent prior to biological treatment recovers the oil in a sludge much easier and less costly to handle that if the oil is commingled in a waste activated sludge. Waste activated sludge is costly enough to dewater but when commingled with oil, the oil blinds precoat filters, increases significantly the volume of waste sludge to be dewatered, and makes the final disposition of dewatered oily sludge more troublesome.

Equalizing feed quality in terms of organic loading also can be achieved by filtration or DAF as shown for BOD/COD data in Figures 8 and 9. Colloidal and suspended matter contributes significantly to the total BOD/COD and periods of storm flow which flushes sludge and silt from sewers, high pH, loss of emulsifiers, coke fines, clay fines, etc., typically give a highly variable raw waste load which is frequently underestimated because of sampling and testing difficulties. Removal of the discontinuous phase contaminants can have a large impact on reducing the total organic load and the variability in quality of water entering secondary treatment.

Equalizing the organic loading results in substantial savings in capital and operating costs, simpler operations, and better effluent quality with less variability in quality of water leaving the secondary treatment facilities. For example, data from Figures 7, 8, and 9 are as follows:

| Contaminant | Treatment After | % Probability Less Than Indicated Value | | |
|---|---|---|---|---|
| | | 50 | 95 | 98 |
| Oil and Grease, mg/l | Primary | 70 | 600 | 800 |
| | Intermediate | 4 | 10 | 12 |
| BOD, mg/l | Primary | 185 | 380 | 400 |
| | Intermediate | 80 | 96 | 105 |
| COD, mg/l | Primary | 400 | 980 | 1,400 |
| | Intermediate | 220 | 310 | 350 |

An engineer faced with design of an ASU to operate in the nitrification mode at 2 mg DO/l with uniform effluent quality faces an almost insurmountable challenge, both economically and performance-wise, if he has to deal with the variability of the raw waste load. Considering that data in the preceding table represent a year of operations, they also reflect (1) seasonal, (2) weekly, (3) daily, and (4) hourly cycles. The final design of an ASU based on primary effluent would be such a compromise that year-round operation would be unsatisfactory, yet the unit would be expensively over-designed. If, for example, a guideline of 1 lb. $O_2$/lb. COD is used and the 98% COD value is selected as design basis, the raw waste would require four times the aeration horsepower the intermediate treated waste does. Actually, it would require substantially more, because the alpha (oxygen transfer) characteristics of the raw waste are only about one-half as good as the intermediate treated waste.

### Filtration or DAF of API Separator Effluents Simplifies ASU Process Control

The amount of colloidally dispersed inert solids and oil entering the aeration tank affects the degree of process control available to the operator. Colloidal and suspended matter in the influent to the ASU at quite low concentration levels can make the process nonoperable at the optimum conditions.

The ASU process control is via the food-to-microorganism (F/M) ratio, or perhaps more practically the sludge age (SA). The sludge age and F/M ratio are related as follows:

$$\frac{1}{SA} = \frac{a\,(\Delta F/\Delta T)}{M} - b \qquad \text{(Equa. 2)}$$

where,
$a$ = the sludge yield coefficient,
$b$ = the endogenous rate coefficient,
$M$ = the mass (lbs) of microorganisms in the system,
$SA$ = the sludge age (days), and
$\Delta F/\Delta T$ = the mass (lbs) of food (BOD or COD) supplied per day.

The F/M process control involves measurement of the BOD or COD load ($\Delta F/\Delta T$) per day and adjustment of the sludge inventory (M) to maintain a desired ratio. The sludge age method of process control can provide a simple hydraulic means to achieve the same end by sludge wastage. The sludge wastage rate to maintain an indicated sludge age is calculated from the equation:

Wastage (MGD) =

$$\frac{1}{X_r - X_e}\ \frac{(V_A + V_c)\ X_A}{SA} - QX_e \qquad \text{(Equa. 3)}$$

where,
$X_r$ = sludge concentration in recycle
$X_e$ = sludge concentration is effluent
$X_A$ = MLSS
$V_A$ = volume of aeration tank, MMGD
$V_c$ = volume of clarifier, MMG
$Q$ = feed volume, MMGD

The sludge age method of process control has many advantages which are discussed in detail by Walker (4).

The accumulation of negatively charged colloids, inerts and oil in the activated sludge mass is hypothesized to be a principal cause of poor sludge setting properties (SVI) and dispersed solids, thereby limiting the effective SA or F/M operating range. The sensitivity of the ASU to influent inert solids can be readily demonstrated. For example, if undesirable materials such as heavy oils, catalyst fines, clay, coke fines, metallic sulfides, etc., escape preceding treatment at the rate of 30 mg/l, become flocculated by activated sludge and accumulate, their effect can be predicted. Assuming for simplicity of calculation that the inerts can escape only via sludge wastage and not via the clarifier overflow, the equilibrium character of the mixed liquor solids can be estimated using equations (2) and (3). These data in Figure 10 show that a fixed amount of entering inert solids accumulate in the total solids mass at an ever increasing rate with increasing sludge age. Inspection of the curve for biological solids shows that operation at high sludge age will result in minimal waste sludge and process control tests and responses.

A more comprehensive discussion of the advantages for complete phase separation is available (5,6).

### Filtration of Raw Intake Water Markedly Reduces Oily Primary Sludges

In a refinery case history involving filtration of raw intake water, removal of intake solids markedly reduced and simplified solid waste problems (6).

Solids in intake water that contacts, or commingles with, plant process water can have a major impact on waste sludge generation. In a refinery, for example, a make-up water containing about 120 mg/l suspended solids contributed 25,000 lbs/D solids to the plant system. A solids material balance around primary treatment comparing the cases of intake solids removal with no removal is included in Figure 11. In this example, removal of intake solids by filtration reduced the amount of wet, oily primary sludges generated by more than 85%.

Solids removed from intake water by filtration don't, of course, just disappear. Direct filtration of raw water using only polyelectrolytes for colloid destabilization yields filter backwash solids so receptive to modest chemical treatment that further mechanical dewatering cannot be justified. Combining these backwash solids with lime softening sludge yields a significant chemical and dewatering synergism such that by combining sludges at least 25% less thickened sludge volume is produced. The flocculation and dewatering action of combined sludges is virtually instantaneous (6).

**Overall Impact of Filtration on a Refinery Water Management Program**

The overall impact of filters on a refinery water management program can be illustrated by comparing the amount, and kind, of sludges generated in two refinery cases: one involving filtration of activated sludge plant effluent only, and the second involving filtration of intake water, primary effluent, and activated sludge plant effluent.

The amounts of sludges generated in the two cases are shown in Table 1 for a case history. The use of three filtration steps reduced the amount of sludges generated by more than one-half that of the single filter case. Removing intake solids at the source resulted in a major, net reduction of primary and intake sludges, and removing primary solids resulted in a major, net reduction of waste activated and primary sludges.

Not only is the amount of sludge generated significantly reduced by the three stages of filtration, but even more important from a handling and cost basis is the fact that the sludge properties are much improved as outlined in Table 2. As shown the generation of the large amount of oily, secondary sludges with the noxious handling problems previously described can be avoided. For a major, integrated water management program, therefore, the use of three stages of filtration can result in very large capital and operating cost savings of ancillary facilities for sludge thickening, dewatering, and disposition. Additionally, savings accrue from the more modest secondary facility requirement because of the major reduction in raw waste load achieved by the filtration of primary effluent, and the more favorable mode of activated sludge unit operation. (5)

**Bioenhancement**

With reference to Figure 6, effluent standards for 1983 (best available technology economically achievable, BATEA), are predicted upon addition of a stage of granular carbon treatment to the 1977 best practicable technology currently achievable (BPTCA) treatment sequence. Addition of granular carbon to the BPTCA sequence will typically double the capital investment and more than double the operating costs of the effluent treatment sequence. In response to this incentive, research by the petroleum industry has recently demonstrated that the BPTCA sequence can be optimized, and the ASU process "enhanced" such that the effluent water quality is equivalent to that treated by a stage of granular carbon.

Part of this research achievement lies in simply responding to the biological kinetic expression of Adams et al (11):

$$S_e = \frac{S_o (S_o - S_e)}{kMt} \quad \text{(Equa. 4)}$$

where, $S_e$ = soluble organics in effluent, mg/l
$S_o$ = organics in influent, mg/l
k = kinetic constant
M = biomass, mg/l
t = aeration time

Since $S_o$/Mt is the F/M (food/micro-organism) ratio, letting F = F/M equation 4 becomes:

$$S_e = S_o (kF^{-1} + 1) \quad \text{(Equa. 5)}$$

For best effluent quality from the ASU, equations 4 and 5 say that $S_o$ and F should be minimized. Or, from equation 2, the sludge age (SA) should be maximized. The most important means for minimizing $S_o$ is to remove essentially all colloidal matter remaining after primary treatment (Figures 7, 8, and 9). Once this is achieved F can be minimized (SA maximized) because the biological floc properties (Sludge Volume Index) *do not deteriorate* with increasing sludge age. This is illustrated in Figure 12 where the SVI properties of activated sludge from a unit with prefiltered feed is compared to literature data for unfiltered feed (12).

Some recent data from two refineries are available treating refinery effluents according to the BPCTCA sequence (Figure 5) in which the performance of a unit passing colloidal solids to the ASU was compared to the performance of a parallel treatment in which the colloids where removed:

| Parameter | % Improvement with Colloid Removal |
|---|---|
| Refinery A | |
| Soluble organic carbon | 20.5 |
| Soluble chemical oxygen demand | 31.1 |
| Suspended solids | 81.7 |
| Phenolics | 59.8 |
| Refinery B | |
| Soluble organic carbon | 26 |
| Soluble chemical oxygen demand | 33.7 |

These data demonstrate that removing colloids essentially completely prior to activated sludge treatment of the residual solubles yields a significant improvement in effluent quality. The principle subject of this article, therefore, is to address the chemistry of these colloids to illustrate how their removal can be optimized by granular media filters or DAF units.

## Properties of Suspended Solids

Refinery effluents from API separators, aerated lagoons, fire and cooling water ponds, etc., are similar to surface waters in that the suspended materials usually are predominantly colloidal, or a combination of colloidal and very slightly flocculated suspensions. The stability of these colloidal systems relates to the fact that the individual particles carry like electrical charges, causing their mutual repulsion. Except for some very isolated examples, the charge on organic, inorganic, and biocolloids is negative when suspended in water. Colloidal destabilization by chemical treatment has the objective of neutralizing, or reducing, the electrical charge so that mutual repulsion is reduced to the extend that individual particles can approach each other close enough for van der Waals and/or chemical forces to become effective. The attractive van der Waals forces cause the particles to aggregate into agglomerates, which facilitates their removal by sedimentation, DAF, or filtration processes. The surface charge on colloidal particles may be estimated by electrophoretic, electroosmotic, streaming and sedimentation potential techniques.

We have found that the electrophoretic procedures and equipment of Riddick (7) permits the rapid determination of colloidal charge to be made and all our investigations involved use of the Zeta Meter. Accordingly, electrokinetic values reported herein are zeta potentials (ZP).

## Colloid Destabilization Mechanisms

Destabilization of the waterborne suspended solids may involve four mechanisms: (1) colloid entrapment or removal via the sweep floc mechanism, (2) reduction in surface charge by double layer repression, (3) bridging by polymers, and (4) charge neutralization by adsorption.

### Colloid Entrapment

Colloid entrapment involves chemical treatment with comparatively massive amounts of primary coagulants; the amount of coagulant used is typically so great in relation to the amount of colloidal matter that the nature of the colloidal material is not relevant. The amount of primary coagulant used may be 5 to 40 times as much as is used for charge neutralization by adsorption. The rate at which the primary coagulants form hydrous metal oxide polymers (Figure 12) is relatively slow and depends chiefly upon water temperature and pH. Coupled with the high conentration used, all negatively charged colloidal material is initially exposed to charge neutralization by the transient cationic species. The polymer matrix is 3-dimensional and voluminous, as illustrated by Figure 14, providing for entrapment of solids. As the polymer contracts, freeing solvent water molecules, and settles, the suspended solids remain enmeshed in the settling floc and appear to be swept from the water, hence the description of the process as a "sweep floc" mechanism. This destabilization mechanism results in the generation of large amounts of wet alum (or iron) sludges, which are difficult and costly to dewater. Even though it is by far the most widely used mechanism for water clarification *it is to be avoided* in granular media filtration and DAF because of the sludge problem and because the use of other mechanisms result in significantly lower operating and capital costs. In the case of direct filtration, the comparatively massive chemical treatment used in this destabilization mechanisms rapidly blinds the filter, causing very short runs.

### Double Layer Repression

Reduction in surface charge by double layer repression is caused by the presence of an indifferent electrolyte, which in refineries is chiefly sodium chloride from brackish water usage or salt water ballast. For water and monovalent electrolytes, the thickness of the double layer is approximately 10 Angstroms ($A_o$) for 0.1M, 100$A_o$ for 0.001M, and 1000 $A_o$ for 0.00001M. For double layer repression of colloid surface charge in brackish waters, the sodium ions of the indifferent electrolyte, which surrounds the colloid particles in order to electrically balance their negatively charged surfaces, have less tendency to diffuse away from the colloid surface as the salinity increases. Some salt concentration may eventually be reached such that the thickness of the double layer may be small enough that two colloids approach each other closely enough that van der Waals forces cause aggregation. An important aspect of double layer repression is that the quantity of colloidal charge is not significantly reduced, but just the extent to which it extends out from the colloid surface. This relates to the nature of the destabilizing chemical (salt) and its mode of action; i.e., the sodium ions remain free in the solvent and cause rapid dissipation of the charge as the distance from the colloid surface increases. Double layer repression can improve solids removal by direct filtration, but this mechanism does not achieve the best results and can conceal definition of optimal chemical pretreatment to achieve best filtration results if the interference of this destabilization mechanism is not recognized. Our refinery experience indicates that the colloidal aggregates destabilized by double layer repression are readily redispersed by hydraulic forces as if the net binding forces are very weak.

### Bridging

Bridging by organic and inorganic polymers describes the destabilization mechanism where the molecules of the added chemical attach onto two or more colloids causing aggregation. Cationic polyelectrolytes up to about 10,000,000 molecular weight are available for this service. Weakly anionic organic polymers are negatively charged; however, they are useful for aggregating and binding together some moderately negatively charged aggregates into agglomerates that resist redispersion. Thus, in this latter instance, attractive forces of a chemical nature overcome moderate electrostatic repulsion forces due to like charges. *Bridging by polymers proved to be an important destabilization mechanism for application to direct filtration and DAF.*

### Charge Neutralization

*Charge neutralization by adsorption of the destabilizing chemical to the colloid is* *a key mechanism for optimizing removal of waterborne solids from waters by direct filtration.* Perhaps adsorption is a poor word choice here, since the mechanism may not be different from bridging previously discussed. While the mechanism may be the same, the end results are different in that the colloidal charge may not only be reduced to zero, but beyond zero, i.e., reversed. Charge neutralization by adsorption infers that the colloid-water interface is changed and thereby its physicochemical properties.

## Destabilizing Chemicals

### Primary Coagulants

Efficient destabilization of colloidal suspensions using salts of iron and aluminum as primary coagulants must recognize the properties of these primary coagulants. The chief properties of concern are the ZP-pH relationships and hydrolytic reactions.

Stumm and O'Melia (8) describe the equilibrium composition of solutions in contact with precipitated primary coagulants in the interesting manner shown in Figures 15 and 16. These diagrams are calculated using constants for solubility and hydrolysis equilibria. The shaded areas A and B we have added in each figure are approximate operating regions for air flotation and clarifiers by colloid entrapment (region A) and direct filtration by charge neutralization (region B). Both regions are assumed to cover a pH range of 6.0 to 8.5. The coagulant dosage ranges from 33 to 200 mg/l in region A and 3.3 to 20 mg/l in region B. These figures are useful in the interpretation of some of our filtration results.

With reference to Figure 16, the isoelectric point for ferric hydroxide coincides with the region of minimum solubility, and the operating regions for water treating (destabilization) yield a hydrolyzed primary coagulant with a desirable positive zeta potential.

In many refinery situations, however, it is difficult to use this attractive condition because the presence of sulfides and strongly reducing conditions cause the reduction of ferric to ferrous iron and the formation of mixed iron sulfides with no coagulation powers. In fact, in some refinery waters the use of iron coagulants at modest dosages may contribute to stabilizing solids rather than destabilizing them.

While alum has no redox or sulfide chemistry comparable to iron, it's amphoterism and solubility pose definite limitations on alum usage. With reference to Figure 15, a substantial portion of operating region B lies in the area where alum is soluble and the predominant equilibrium specie is negative, Al $(OH)_4$. In the more acidic part of region B, however, the concentrtion of equilibrium ionic species is very much lower, and much less negative. Considering these data, it is not unexpected that investigators consistently report optimal coagulation/flocculation results with alum at a pH of 5-6.

With inspection of Figure 15, one may question why alum is effective at all for neutralizing negatively charged colloids in the indicated operating regions. One approach to explaining observed performance requires understanding that the data are equilibrium data; but before equilibrium is reached, substantially different conditions exist.

Alum very readily hydrolyzes to form polymers in a complex manner not well defined. The hydrolytic pathway and reaction rates are affected by pH, temperature, other ions, etc. One hypothesized route which includes different aluminum hydrolysis products which are known to exist is outlined in Figure 13. When alum is added to water in amounts which exceed the solubility limits, sequential kinetic reactions occur until the ultimate precipitate is formed and the ionic species appropriate to the pH equilibrate with the precipitate. The hydrolytic reactions are not instantaneous, and as they proceed positively charged hydroxo polymers are formed which are available for colloid adsorption. The hydrolyzed species have enhanced adsorption capabilities, possibly due to larger size and less hydration and the presence of coordinated hydroxide groups (8). In solutions more alkaline than the isoelectric point the positively charged polymers are transient and, at equilibrium, anionic polymers prevail.

In modestly alkaline solutions the transient positively charged polymers appear to contribute to destabilization of colloids. On the other hand, in solutions more acidic than the isoelectric point the positively charged polymers prevail at equilibrium and destabilization of colloids may be achieved at significantly lower coagulant treatment levels.

In Figure 17 the zeta potential of colloidal iron hydroxide fresh water solutions is plotted as a function of pH. The zeta potential decreases in positive charge as the pH increases until the isoelectric point is reached at a pH of 8.3 at which the charge reverses. In the vicinity of the isoelectric point the charge may vary as indicated. Alum has a similar fresh water zeta potential -pH relationship as shown in Figure 18. The zeta potential may be negative or positive over the pH range of 7.0 to 7.8.

### Surfactants

Certain substances, even when present in very low concentrations, possess the unique property of altering the surface energy of their solvents to an extreme degree. Almost always, a lowering rather than an increase of the surface energy is affected. Substances or solutes possessing such properties are known as surface-active agents or surfactants and their unique effect is known as surface activity.

By broad definition then, surface-active chemicals are soluble substances whose presence in solution markedly changes the properties of the solvent and the surfaces they contact. They are categorized according to the manner in which they dissociate or ionize the water and are characterized, structurally, by possessing a molecular balance of a long lipophilic, hydrocarbon "tail" and a polar, hydrophilic "head."

Surfactants owe their physicochemical behavior to their property of being adsorbed at the interface between liquids and gases (where they contribute to the electrical charge on the DAF bubble), or liquid and solid phases (where they may contribute to the zeta potential). Surfactants tend to concentrate in an oriented manner, at the interface, in such a ways that, almost entirely, they turn a majority of their hydrophilic groups toward the more polar phase and a majority of their lipophilic groups away from the more polar phase and perhaps even into a nonpolar medium. The surface active molecule or ion, in a sense, acts as sort of a bridge between two phases and makes any transition between them less abrupt.

There are three types of chemical surface-active agents which are classified according to their dissociation characteristics in water. These are:

1. *Anionic Surfactants*—Where the electrovalent and polar hydrocarbon group is part of the negatively charged ion, when the compound ionizes:

ANIONIC

$CH_3(CH_2)_{16}COO^{-}Na^{+}$

2. *Nonionic Surfactants*—Where the hydrophilic group is covalent and polar and which dissolves without ionization:

NONIONIC

$CH_3(CH_2)_{16}\ COO(CH_2CH_2O)H$

3. *Cationic Surfactants*—Where the electrovalent and polar hydrocarbon group is part of the positively charged ion when the compound ionizes:

CATIONIC

$CH_3(CH_2)_{17}NH_3^{+}CL^{-}$

Surfactants are powerful charge neutralizers (and charge reversers). In the petroleum industry anionic surfactants are used as emulsifiers for asphalt by imparting a zeta potential on asphalt particles ranging from -30 to -80mV. Cationic types impart a zeta potential ranging from +18 to 128 mV. Each surfactant possesses a distinct characteristic capability of imparting quantitatively to asphalt during emulsification a specific zeta potential.

Surfactants have not found wide use for destabilizing colloidal systems. In fact, they are an important cause for the existence of colloidal systems, particularly in primary municipal effluents. The principal organic colloidal destabilizing chemicals are polyelectrolytes.

**Polyelectrolytes**

Polyelectrolytes used as water treating chemicals are macromolecules having many charged groups and may be classified as cationic, anionic, and nonionic depending upon the residual charge on the polymer in solution. Examples of the structural types are shown in Table 3.

In solution the polyelectrolytes are dissociated into polyvalent macroions and a large number of small ions of opposite charge (counter ions). The macroion is highly charged, which is the cause for the characteristic properties of the polyelectrolytes. Most of the macroions are long, flexible chains, their size and shape depending on the macroion charge and interaction with counter ions. With increasing charge the macroion extends; with decreasing charge the macroion assumes a contracted random coil. The source of the charge is illustrated by the polyacrylates, a widely used polymer. In distilled water polyacrylic acid's carboxylic functional group is only slightly dissociated. The addition of NaOH reacts with the carboxylic acid groups causing them to dissociate leaving a charge on the macroion and producing sodium counter ions as shown in Figure 19.

The number of monomers in a polyelectrolyte may range from about $10^2$ to $10^5$. In the case of polyacrylic acid the length of each monomer along the chain is 2.5A° (Angstroms). Since the radius of each atom is about 1A°, a polymer macroion is envisioned as a flexible cylinder like a garden hose. The flexibility of the macroion exists because bonds in the main chain can rotate around the neighboring bond keeping the bond angle constant, the macroion has, therefore, a very large number of conformations classified as either random coil or helix (extended). In the random coil there is no long range regularity in the bond angles. In the helix the chain bond angles have a long range regularity.

**The Dimensions Involved**

The dimensions of the various components involved in colloid destabilization vary a million-fold, from a few A° to more than $10^6$ A° as shown in Table 4.

Where color is not a significant factor, the problem is usually one of causing colloidal particles down to about 1000 A° in diameter to aggregate. When a clarifier or DAF is used for phase separation, it is desirable to build aggregates to fairly large size, say greater than $10^6$A°. On the other hand, when filters are used simply destabilizing the colloidal particles is sufficient, because the destabilized particles will build aggregates in the filter bed as the destabilized suspension passes through the media and the particles impinge and adhere to the media or trapped suspended matter.

## Systematic Approach to Determining Chemical Treatment Requirement

Broad experience in refinery effluent treatment led to outlining the condition-response schematic for chemical treatment of waterborne colloids shown in Figure 20. In phase removal by filtration, or even DAF, we are not concerned with, and indeed it is desirable to avoid, the use of (1) the "sweep floc" or colloid entrapment, and (2) the double layer repression mechanisms for colloid destabilization. Destabilization efforts must focus on the charge neutralization and bridging mechanisms. Charge neutralization correlated with plant performance as the optimum destabilization mechanism. For plant control of direct filtration, charge neutralization has been the key test parameter correlating with performance of refinery filters. Brackish water required that charge neutralization be measured after dilution with distilled water to separate the effects of double layer repression and charge neutralization; i.e., under plant conditions of high salinity, the addition of destabilization chemicals could reduce the ZP to approximately zero by a range of chemical treatments; however, when double layer repression was the cause of reduced ZP, reduced filter run lengths and performance were observed. Reducing the ZP to approximately zero, as measured by means responsive to charge neutralization, point out more definitely the required destabilization chemical treatment and resulted in optimum filter performance.

Waterborne colloids subject to chemical destabilization and phase separation fall into two general categories: relatively inert substances such as clays, sand, and organic materials; and microorganisms or biocolloids. Both categories of colloidal matter may be stabilized because they are charged and/or are highly hydrophilic. Both categories of colloidal matter also may vary in response to treatment by destabilization chemicals, and within each category the state of subdivision seems to require additional consideration; i.e., extremely small colloidal particles are sometimes more difficult to aggregate for removal by filtration. Typically, destabilization of biocolloids, such as are in aerated lagoon effluents, is a more demanding problem.

In the case of polyelectrolytes, some counter ions at high concentrations screen the charged functional groups with an ionic cloud as previously described. Salinity, hydroxide, phenolics, sulfides, etc., are examples of the kind of counter ions found to affect various cationics. Each waste water application of cationics must address the contaminants present if the most cost-effective polyelectrolyte is to be used (9).

**Titration Curves**

A comparison of polyelectrolyte performance and determination of antagonisms and synergism is conveniently and quantitatively determined by use of ZP titration curves. Because the stability of a suspension is determined by the balance between the short range (van der Waals) attractive forces and the repulsive coulombic forces between the particles, the objective of ZP-cationic polyelectrolyte titration curves is to quantify the amount of polyelectrolyte needed to reduce the repulsive coulombic forces to levels that permit total destabilization by attractive forces (10).

ZP titration curves were determined using the equipment of Riddick (7). Increments of regent are added to the water being investigated, mixed and recirculated through the electrophoretic mobility cell for two minutes, and then the ZP determined. Plotting the data points yield ZP titration curves as in Figure 21 which show the effect of pH on the charge reversal properties of two good cationics. In this example, when compared to pH 8, the cationic 1190 is synergized and C-31 is antagonized at pH 10.

The sensitivities of the two other good cationics to pH and phenol are shown in Figures 22 and 23. These data show that 431 is not significantly affected by phenol; however, phenol not only antagonizes 581 at a pH of 7.8, but overcomes a pH synergism and antagonizes 581 at a pH of 10.

Biocolloids, being quite hydrophilic, can be more challenging a problem if tough, stable aggregates are required (1). Example ZP titrations for biocolloids in aerated lagoon effluent are shown in Figure 24.

The cationics in Table 5 are listed in order of the amount required to reach zero zeta potential. This "end-point" is somewhat arbitrary since many colloid systems are destabilized adequately for phase removal when the zeta potential is only reduced to -5 or -3 mV.

Comparative rankings at these other "end-points" are also shown. A summary of polyelectrolyte synergisms and antagonisms to salinity, pH and sulfides is shown in Table 6 (9).

While the most cost-effective chemical treatment would be to use just enough to reduce the ZP to permit van der Waals forces to predominant, in some cases at least it is not necessary to "titrate" the chemical addition this carefully to achieve excellent results; i.e., a minimum amount of chemical usage may be determined but adding too much is not harmful.

Consider the refinery problem of the aggregation of coke fines in hydraulic decoking water so they are readily removable. As shown in Figure 25, coke fines are originally stabilized by a negative ZP, but the negative charge is readily neutralized and reversed by cationic polyelectrolytes. One might think that too much cationic would simply restabilize the system as a positive colloid. However, using a cationic that has good *bridging* properties in addition to *charge* neutralization causes most of the solids to be enmeshed by the polymer. The larger size aggregates are more readily separable even though comparatively highly charged. As shown in Figure 25, addition of a small amount of high molecular weight weakly anionic polyelectrolyte to the positively charged cationic treated coke particles will once again reverse the charge. Rather than redisperse the particles, however, the weakly anionic polymer efficiently "collects" the positively charged particles into massive aggregates easy to separate; i.e., once the high molecular weight weakly anionic polymer establishes bonds with the solids and forms aggregates, the aggregates are bound together with strong enough forces to resist redispersion by hydraulic forces in a clarifier, filter or DAF unit (9).

## Summary and Recommendations

### Chemical Destabilization

API separator effluents and other refinery waste streams contain the kinds of suspended matter that respond to rather simple chemical treatment.

Destabilization is achieved by using the proper amount of an effective cationic polyelectrolyte to achieve charge reduction. The destabilized aggregates are then agglomerated by using a weakly anionic polyelectrolyte such that the agglomerates are not redispersed by hydraulic forces in the filters used for phase separation; 0.02 to 0.05 mg/l anionic polyelectrolyte is the expected concentration range for anionics. For DAF units the cationically destabilized aggregates are agglomerated into tougher flocs by using about 0.5 mg/l of a weakly anionic polymer. The most widely applicable weakly anionic polymer is a polyacrylamide polymer of about 15,000,000 molecular weight with from 5 to 10% of the amide groups hydrolyzed.

**Granular Media Filtration and DAF**

If the chemical destabilization recommendations are followed, the hydraulic loading limitations of most commercially available granular media filters relate chiefly to 1) the nature of the destabilized aggregates, and 2) water temperature during filtration.

Two extremes pointing out the importance of the nature of the destabilized suspended matter are the data for coke fines (Figure 24) and biocolloids. Coke fines form large, nonblinding, tough agglomerates that resist redispersal with proper chemical treatment. Very high hydraulic rates are expected with agglomerates with these characteristics. On the other hand, an intrinsic property of biocolloids is their hydrophilicity which makes their chemical destabilization more challenging. Even with optimized chemical pretreatment, destabilized aggregates of hydrophilic solids are especially sensitive to the temperature of filtration because the chemical forces binding the aggregates are not as strong as for hydrophobic colloids. The hydraulic loading-temperature guidelines recommended for this most challenging case are shown in Figure 26.

For DAF units a flash mix (1-2 minutes) and flocculation zones (10-15 minutes) using two chemicals (cationic for destabilization and anionic for flocculation) are recommended pretreatment. A flotation zone loading of 1.5 gpm/ft$^2$ and 30% recycle at 50 psi air pressurization are recommended for optimal phase separation.

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**Grutsch, J.R., and Mallatt, R.C.,** *Hydrocarbon Processing, 55,* No. 6, 115 (1976).

**Grutsch, J. R., and Mallatt, R. C.,** *Hydrocarbon Processing, 55,* No. 5, 221 (1976).

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**Vroblik, E. R.,** *Proceedings 14th Industrial Waste Conference,* Purdue Univ., 1959, pp. 743-779.

## Table 1
# Sludge Balance From Water Treating Operations

| Source of Sludge | Sludges, Tons/Day | |
|---|---|---|
| | Filtration of Activated Sludge Effluent Only | Filtration of Solids From Intake, API Separator, and Activated Sludge Effluents |
| *Treatment of Make-up Water* | | |
| Intake Water, Solids | 0 | (3900) |
| Boiler Water Treatment | (200) | (200) |
| Combined, after Thickening[1] | 200 | 250 |
| *Primary Treatment of Effluent* | | |
| API Separator Sludge[1] | 144 | 19 |
| *Intermediate Treatment of Effluent* | | |
| Filter Backwash Sludge[1] | 0 | 28 |
| *Secondary and Tertiary Treatment* | | |
| Waste Activated Sludge[2] | 562 | 140 |
| **Totals** | **906** | **437** |

[1] *Thickened to 10% solids.*
[2] *Thickened to 4% solids.*

## Table 2
# Kinds and Amounts of Sludge Generated

| Kind | Sludges, Tons/Day | |
|---|---|---|
| | Filtration of Activated Sludge Effluent Only | Filtration of Solids From Intake, API Separator, and Activated Sludge Effluents |
| Inert, Non-contaminated Sludges | 200 | 250 |
| Oily, Primary Sludges | 144 | 47 |
| Non-Oily, Secondary Sludges | 0 | 140 |
| Oily, Secondary Sludges | 562 | 0 |
| **Totals** | **906** | **437** |

Table 3

## Examples of Cationic, Nonionic and Anionic Polyelectrolytes

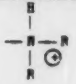
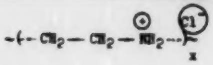
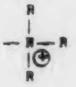
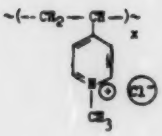
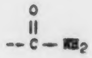
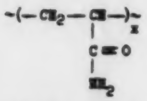
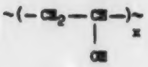
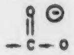
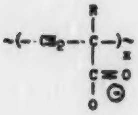
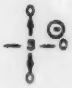
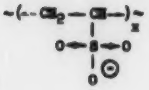
| Polyelectrolyte Description | Structural Type | Functional Group | Example | |
|---|---|---|---|---|
| Cationic | Amines |  |  | Polyethylenimine Hydrochloride |
| | Quaternary |  |  | Poly(N-methyl-4-vinyl pyridinium chloride) |
| Nonionic | Polyamide |  |  | Polyacrylamide |
| | Polyalcohol | —OH |  | Polyvinylalcohol |
| Anionic | Carboxylic |  |  | Poly(meth)acrylic Acid |
| | Sulfonic |  |  | Polyvinylsulfonate |

Table 4

## Dimensions Involved in Colloid Destabilization

| **A. Some Colloidal Systems** | **Diameter, Angstroms** |
|---|---|
| Color Bodies | 50 – 1000 |
| Inert Colloids (Clay, silt, inorganic salts, etc.) | 1,000 – 30,000 |
| Emulsions | 2,000 – 100,000 |
| Bacteria | 5,000 – 100,000 |
| Algae | 50,000 – 8,000,000 |
| **B. Cations** | |
| $Na^+$ | 1.9 |
| $Ca^{++}$ | 2 |
| $Mg^{++}$ | 1.3 |
| $Al^{+++}$ | 1 |
| **C. Polyelectrolytes** | |
| Potential Tunnel | 7 – 11 |
| Chain Length, 100,000 – 15,000,000 M.W. | 250,000 – 40,000,000 |
| **D. Electrical Double Layer** | |
| Range of Expected Values | 5 – 100 |
| Expected Typical in Refinery | 30 |
| **E. Solvent** | |
| $H_2O$ | 4 |

Table 6

## The Comparative Effectiveness of Cationic Polyelectrolytes For Charge Neutralization of Suspended Matter in API Separator Effluents as Determined by Zeta Potential Titration Curves

| Conditions | Polyelectrolyte (a,b) | mg/l to Achieve Indicated ZP Endpoint | | | | Rank at Indicated ZP Endpoint | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | -5 | -3 | 0 | +3 | -5 | -3 | 0 | +3 |
| A. pH = 8; Specific Cond. = 560, and Zero Sulfides. | C-31 | .25 | .5 | .5 | 1 | 1 | 1 | 1 | 1 |
| | 581 | .5 | 1 | 1.25 | 3.75 | 2 | 2 | 2 | 5 |
| | 431 | 1.5 | 1.75 | 2.5 | 3 | 6 | 4 | 3 | 2 |
| | 7132 | 1.25 | 1.75 | 2.5 | 3.25 | 5 | 4 | 3 | 3 |
| | 1180 | 1.5 | 2 | 2.5 | 3 | 6 | 5 | 3 | 2 |
| | 1190 | 1 | 1.5 | 3 | 6 | 4 | 3 | 4 | 8 |
| | 2860 | 2.5 | 2.75 | 3 | 3.25 | 8 | 6 | 4 | 4 |
| | 2870 | 2.25 | 2.75 | 3.25 | 3.75 | 7 | 6 | 5 | 5 |
| | 863 | .75 | 1 | 3.25 | 6.75 | 3 | 2 | 5 | 9 |
| | 7134 | 2.5 | 3 | 3.75 | 4.5 | 8 | 7 | 6 | 6 |
| | 2640 | 2.25 | 3 | 4 | 4.5 | 7 | 7 | 7 | 6 |
| | 751 | 2.25 | 3 | 4 | 5 | 7 | 7 | 7 | 7 |
| | FA | 2.5 | 3.25 | 4 | 5 | 8 | 8 | 7 | 7 |
| | 864 | 5.25 | 7 | 10 | (c) | 9 | 9 | 8 | 10 |
| | 860 | 6.75 | 7.25 | (c) | (c) | 10 | 10 | 9 | 10 |
| B. pH = 9.8; Specific Cond. = 680; and Zero Sulfides. | 1180 | 1 | 1.25 | 1.5 | 2 | 1 | 1 | 1 | 1 |
| | 1190 | 1 | 1.25 | 1.5 | 2 | 1 | 1 | 1 | 1 |
| | 581 | 1 | 1.5 | 2 | 2.75 | 1 | 3 | 2 | 2 |
| | 7132 | 1 | 1.25 | 2 | 3.5 | 1 | 2 | 2 | 3 |
| | 2870 | 1.75 | 2.25 | 3 | 3.5 | 2 | 3 | 3 | 3 |
| | 2860 | 2.25 | 2.5 | 3 | 3.5 | 3 | 4 | 3 | 3 |
| | 863 | 1.75 | 2.25 | 3.5 | 4.75 | 2 | 3 | 4 | 4 |
| | 431 | 3 | 3.5 | 4+ | 4.75 | 5 | 5 | 5 | 4 |
| | 751 | 2.5 | 3.5 | 4.5 | 5.25 | 4 | 5 | 6 | 5 |
| | C-31 | 4.25 | 4.5 | 4.75 | 5.25 | 7 | 6 | 7 | 5 |
| | 2460 | 5 | 5.5 | 6 | 6.5 | 8 | 8 | 8 | 6 |
| | 7134 | 4 | 4.75 | 6 | 7.25 | 6 | 7 | 8 | 7 |
| | FA | 3 | 4.5 | 6.5 | (c) | 5 | 6 | 9 | 8 |
| C. ph =10; Specific Cond. = 4,100; and Zero Sulfides. | 2870 | 2 | 2.75 | 4 | 5.25 | 1 | 1 | 1 | 2 |
| | 431 | 3 | 3.75 | 4.5 | 5 | 3 | 3 | 2 | 1 |
| | 751 | 2.5 | 3.5 | 5 | 6.75 | 2 | 2 | 3 | 3 |
| | 581 | 4 | 4.75 | 5.75 | 6.75 | 4 | 4 | 4 | 3 |
| | 2860 | 5 | 6 | 6.5 | 7.5 | 5 | 5 | 5 | 4 |
| | 7132 | 5 | 6 | 7.25 | 9 | 5 | 5 | 6 | 5 |
| | 2640 | 6.5 | 7.25 | 10 | (c) | 6 | 6 | 7 | 6 |
| | 863 | 7 | 8.5 | 10 | (c) | 7 | 7 | 7 | 6 |
| | C-31 | 4 | (c) | (c) | (c) | 4 | 8 | 8 | 6 |

(a) C-31 (Dow); 581 (Cyanamid); 431 (Dearborn); 7132 (Nalco); 1180, 1190 (Betz); 2860, 2870, 2640 (Calgon); 860, 863, 864 (Hercules); 751 (Mazer), and FA (BASF Wyandotte).

(b) Arranged in order of performance using zero ZP as endpoint.

(c) Indicated ZP not achieved.

Table 5

## Polyelectrolyte Synergisms and Antagonisms to Salinity, pH and Sulfides in API Separator Effluents

| | | mg/1 of Polyelectrolyte Required to Reach Zero Zeta Potential at Indicated Specific Conductance (b) | | |
|---|---|---|---|---|
| **Conditions** | **Polyelectrolyte** | **680** | **4,100** | **11,000** |
| A. Sensitivity to Salinity (Salt) at pH = 10 | 1180 | 1.25 | (a) | 6 |
| | 7132 | 2.25 | 7 | 3.75 |
| | 581 | 3 | 5.75 | 4 |
| | 2860 | 3 | 7 | 3.25 |
| | 2870 | 3 | 5 | 2.75 |
| | 863 | 3.75 | (a) | (a) |
| | 431 | 5 | 4.25 | 3 |
| | 751 | 5 | 6.25 | 4 |
| | C-31 | 5 | (a) | (a) |
| | 2640 | 6.5 | (a) | 3.75 |

| | | mg/1 of Polyelectrolyte for Zero Zeta Potential at | | mg/1 Increase or Decrease (–) |
|---|---|---|---|---|
| | **Polyelectrolyte** | **pH = 8** | **pH = 10** | **at pH = 10** |
| B. Sensitivity to pH Specific Conductance = 570 to 770 | C-31 | 1 | 5 | 4 |
| | 581 | 1.75 | 3 | 1.25 |
| | 7132 | 2.75 | 2.25 | -.5 |
| | 431 | 3 | 5 | 2 |
| | 2860 | 3 | 3 | 0 |
| | 2870 | 3 | 3 | 0 |
| | 1180 | 3 | 1.25 | -1.75 |
| | 1190 | 3.25 | 1.25 | -2 |
| | 7134 | 4.5 | 5.5 | 1 |
| | 751 | 4.5 | 5 | .5 |
| | 2640 | 4.5 | 6.5 | 2 |
| | FA | 4.5 | 10 | 5.5 |
| | 863 | 5 | 3.75 | -1.25 |

| | | mg/1 Polyelectrolyte for Zero Zeta Potential at | | |
|---|---|---|---|---|
| | **Polyelectrolyte** | **0 mg S=/1** | **16 mg S=/1** | **8 mg S=/1** |
| C. Sensitivity to Sulfides at pH = 8 to 8.2. Specific Conductance = 720 | 581 | 1.75 | 14 | 10 |
| | 7132 | 2.75 | 14.5 | (a) |
| | 431 | 3 | 14 | (a) |
| | 2860 | 3 | 16 | (a) |
| | 1180 | 3 | 20 | (a) |

(a) Not determined.
(b) Specific Conductance in micromhos. 4,100 SC = 1.2 gm NaCl 1; 11,000 SC = 3.5 gm NaCl 1.

Figure 1.
**Filter Media**

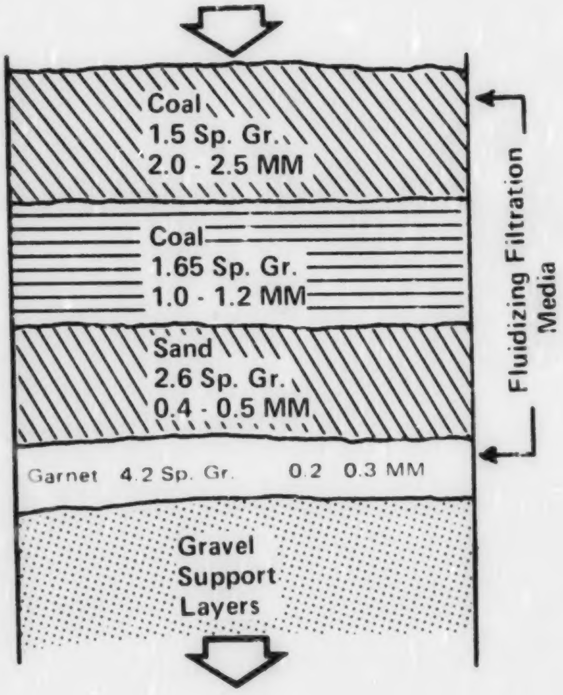

Coal
1.5 Sp. Gr.
2.0 - 2.5 MM
Coal
1.65 Sp. Gr.
1.0 - 1.2 MM
Sand
2.6 Sp. Gr.
0.4 - 0.5 MM
Garnet 4.2 Sp. Gr. 0.2 0.3 MM
Gravel
Support
Layers
Fluidizing Filtration
Media

Figure 2.

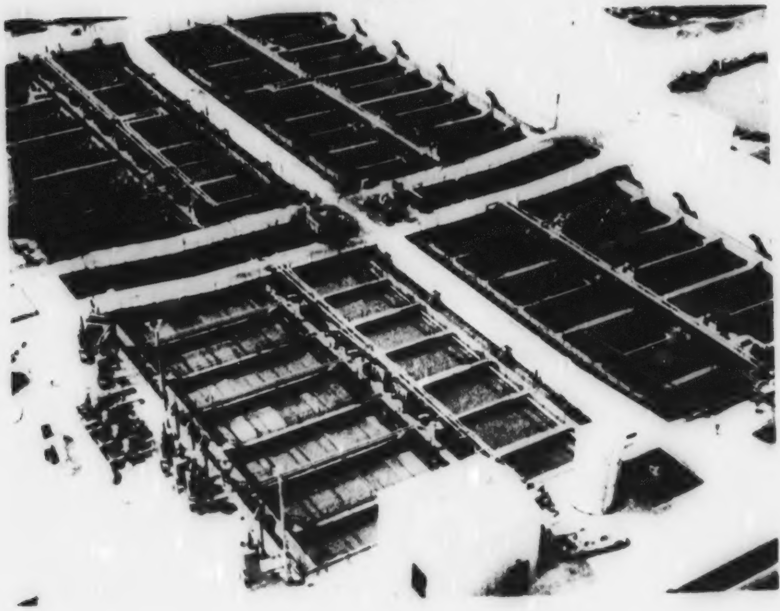


Figure 3.
Flocculator Cell

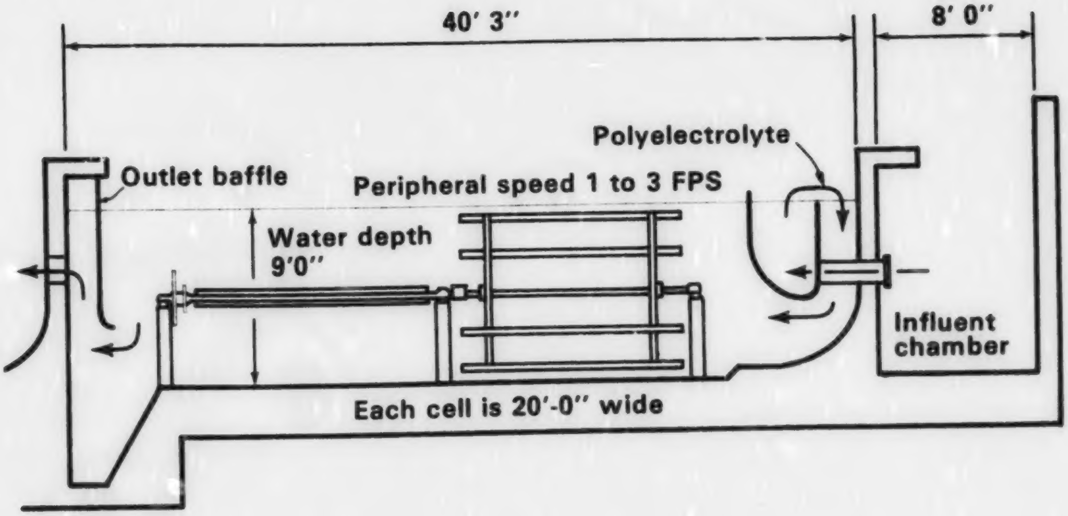

40′ 3″
8′ 0″
Polyelectrolyte
Outlet baffle
Peripheral speed 1 to 3 FPS
Water depth
9′0″
Influent
chamber
Each cell is 20′-0″ wide

Figure 4.
Flotation Chamber

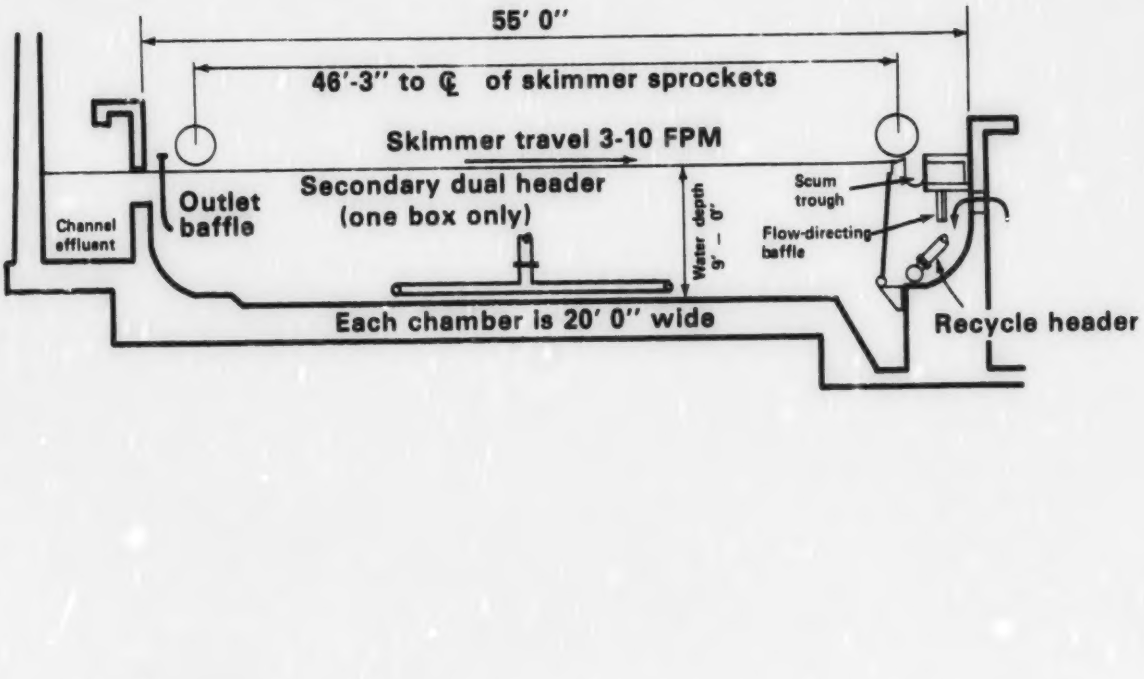

55′ 0″
46′-3″ to ℄ of skimmer sprockets
Skimmer travel 3-10 FPM
Secondary dual header
(one box only)
Outlet
baffle
Channel
effluent
Water depth
9′ – 0″
Scum
trough
Flow-directing
baffle
Recycle header
Each chamber is 20′ 0″ wide

Figure 5.
**Recycle System**

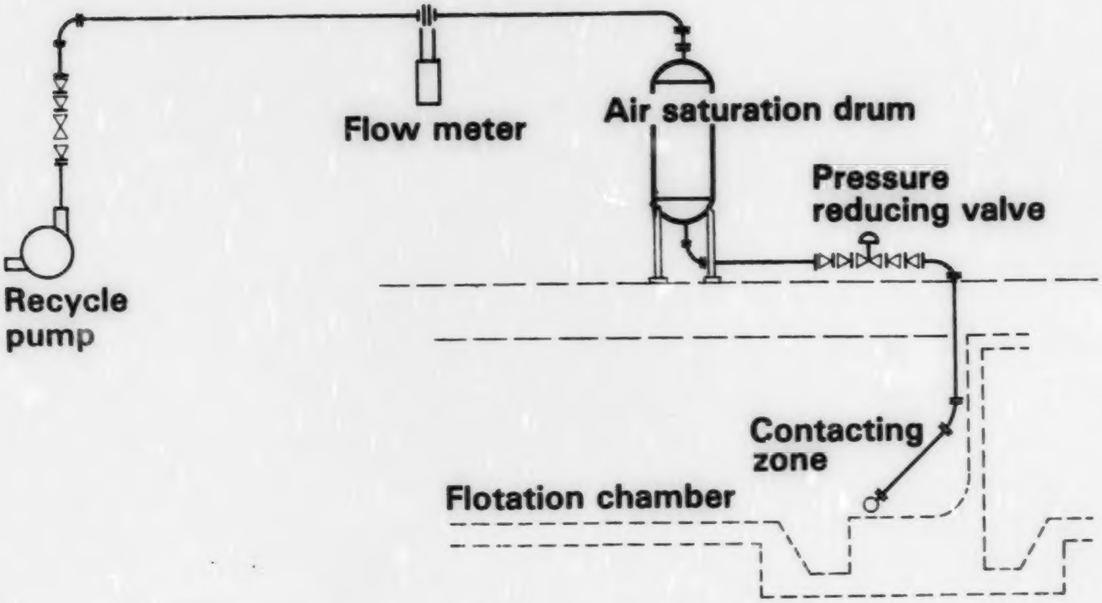

Flow meter
Air saturation drum
Pressure reducing valve
Recycle pump
Contacting zone
Flotation chamber

Figure 6.
**Optional Refinery Treatment Sequence**

| Treatment | Pre or Inplant Treatment | Primary Treatment | Intermediate Treatment | Secondary Treatment | Tertiary Treatment |
|---|---|---|---|---|---|
| Objectives | Phenolics, $S^{=}$, $NH_3$, RSH, $F^{-}$, Acid Sludge, Oil Etc., Removal & Water Reuse or Waste Equalization | Free Oil and Suspended Solids Removal | Emulsified Oil, Suspended and Colloidal Solids Removal | Dissolved Organics Removal | Variable Objectives |
| Processes | Unit Separators<br>Steam Stripping<br>Fuel Gas Stripping<br>Air Oxidation<br>Neutralization<br>Surge Ponds | API Separators<br>CPI, PPI Separators | Chem. Coagulation & Air Flotation<br>Chem. Coagulation & Filtration<br>pH Control<br>Immediate Oxygen Demand Reduction<br>Equalization of Wastes | Trickling Filter<br>Activated Sludge<br>Oxidation Pond<br>Aerated Lagoon | Chem. Coagulation & Air Flotation<br>Chem. Coagulation & Filtration<br>Activated Carbon |
| | | Sludges | Sludges | Sludges | Sludges |

Figure 7.

**Probability Plots of Oil and Grease Data Before and After Intermediate Treatment**

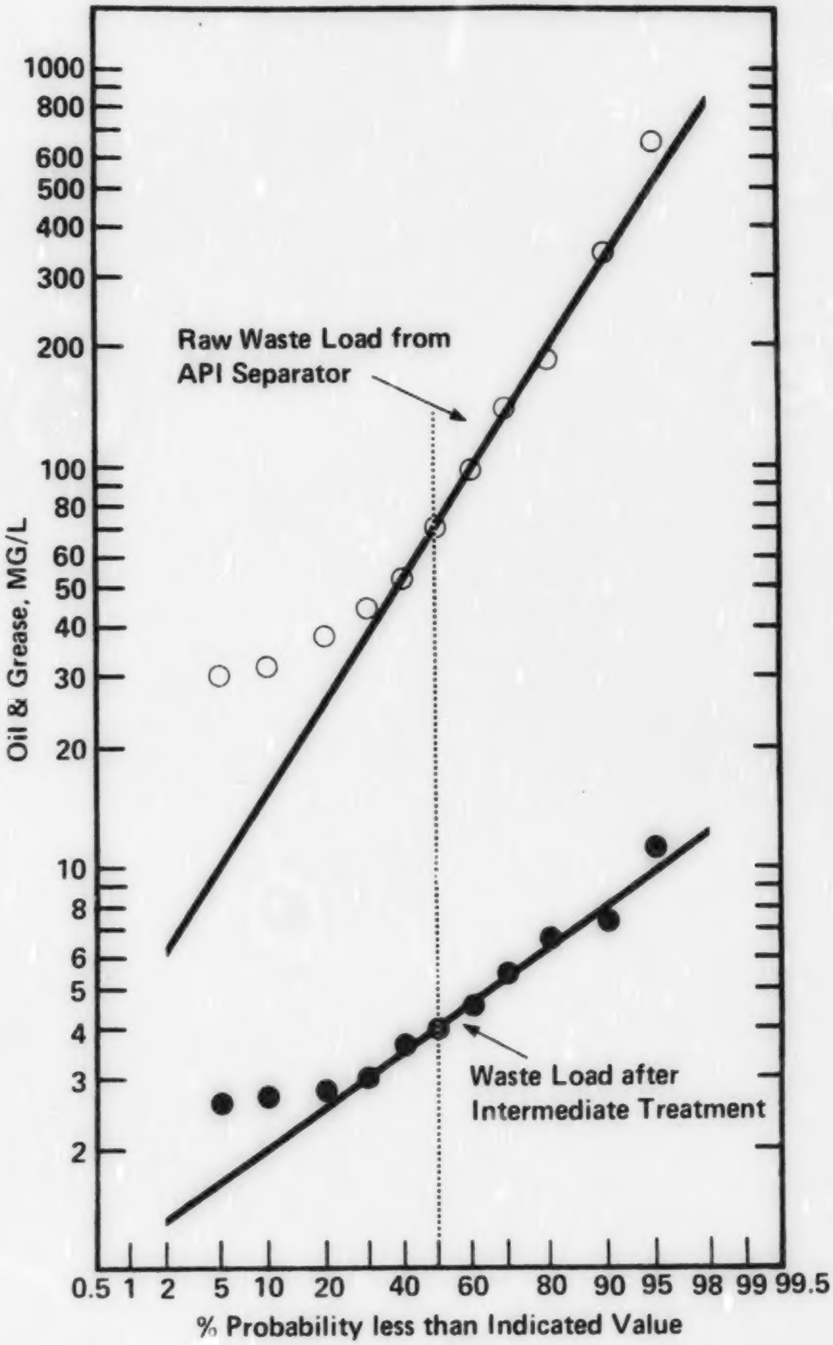


Figure 8.

## Probability Plots of BOD Data Before and After Intermediate Treatment

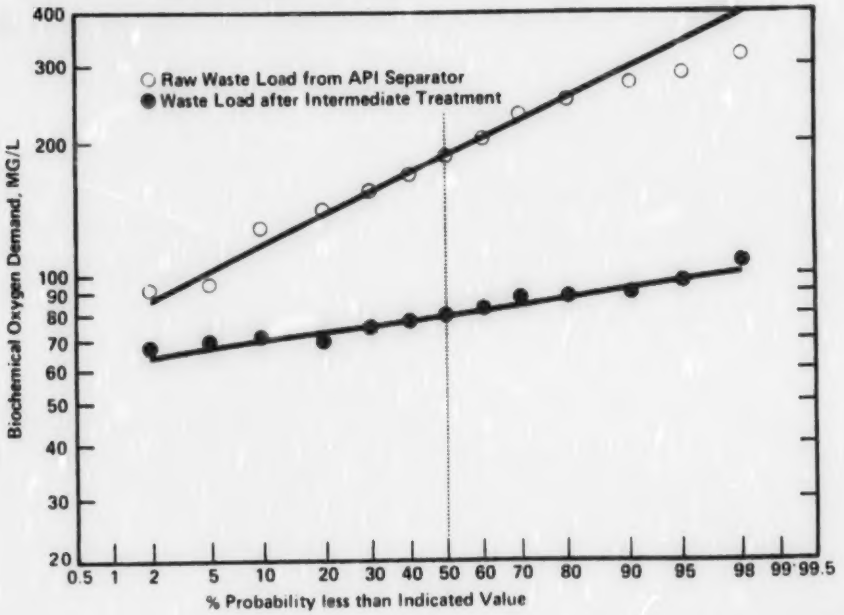


Figure 9.

## Probability Plots of COD Data Before and After Intermediate Treatment

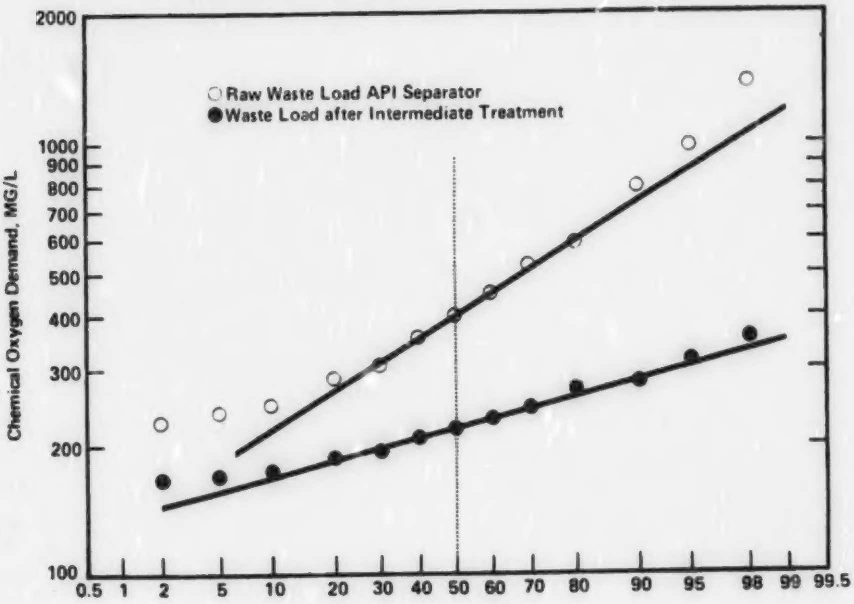


Figure 10.

Character of Mixed Liquor Solids with Sludge Age

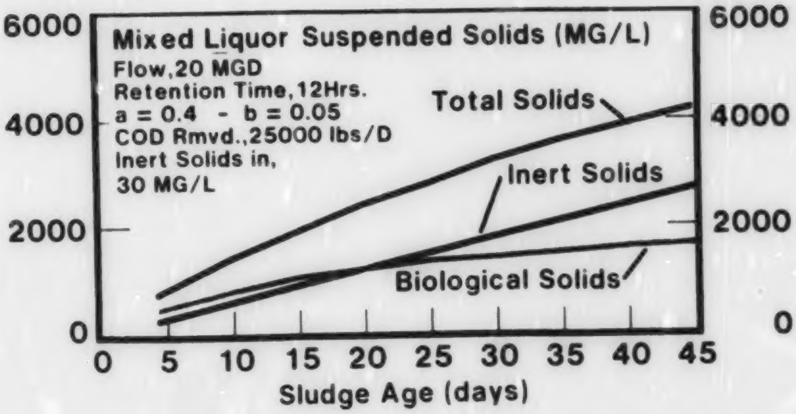
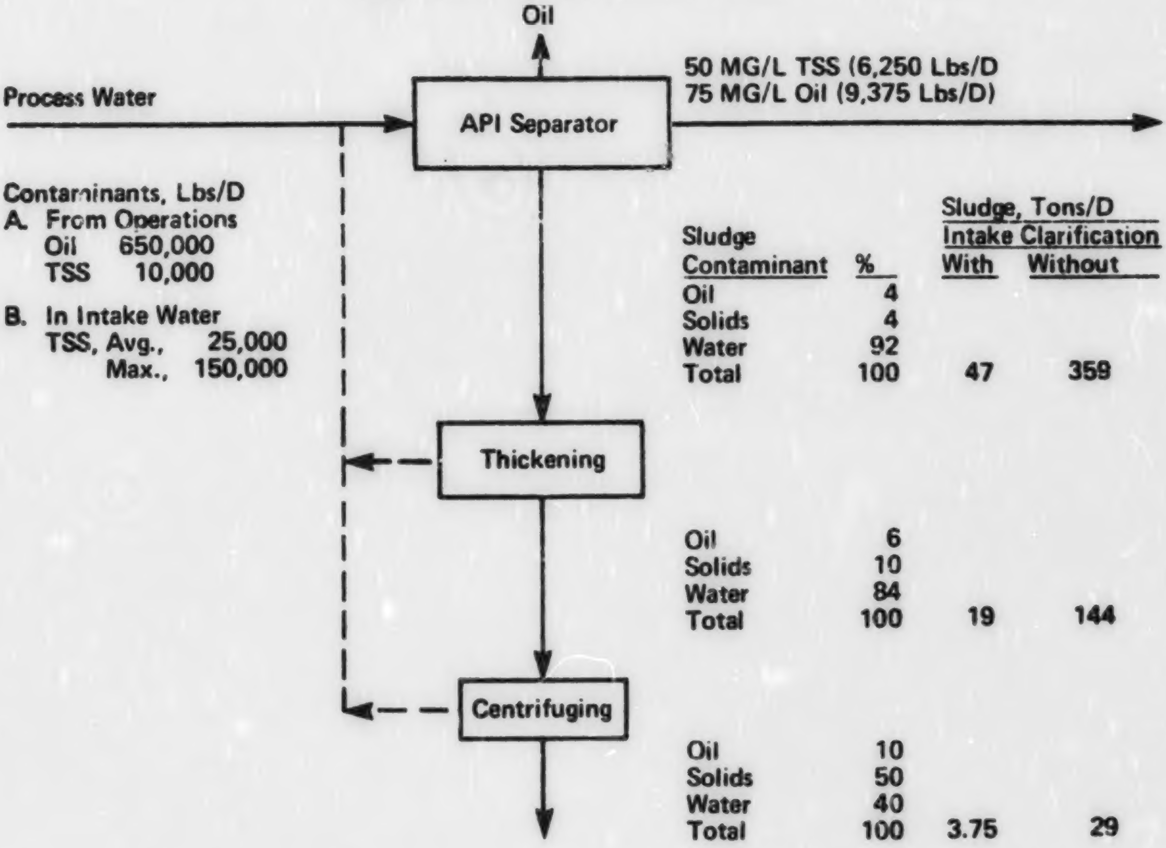


Figure 11.

Effect of Intake Water Solids on Primary Treatment


Oil
Process Water
API Separator
50 MG/L TSS (6,250 Lbs/D
75 MG/L Oil (9,375 Lbs/D)
Contaminants, Lbs/D
A. From Operations
Oil 650,000
TSS 10,000
B. In Intake Water
TSS, Avg., 25,000
Max., 150,000
Thickening
Centrifuging

| Sludge Contaminant | % | Sludge, Tons/D Intake Clarification With | Without |
|---|---|---|---|
| Oil | 4 | | |
| Solids | 4 | | |
| Water | 92 | | |
| Total | 100 | 47 | 359 |
| Oil | 6 | | |
| Solids | 10 | | |
| Water | 84 | | |
| Total | 100 | 19 | 144 |
| Oil | 10 | | |
| Solids | 50 | | |
| Water | 40 | | |
| Total | 100 | 3.75 | 29 |

Figure 12.

**SVI Of Activated Sludge In Unit Treating Refinery Effluent Pretreated by Filtration**

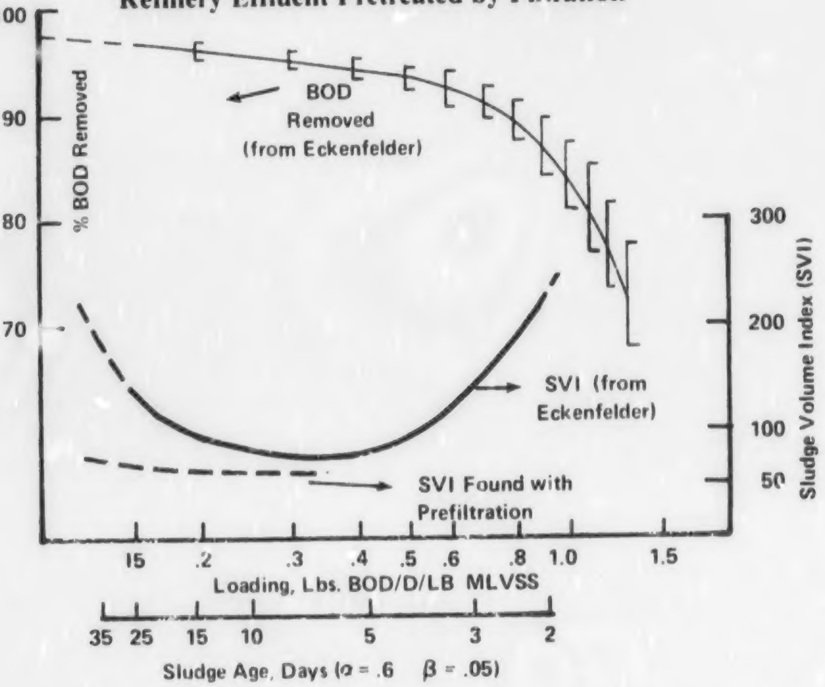


Figure 13.

**Sequential Formation of Hydrous Aluminum Oxide Polymers**

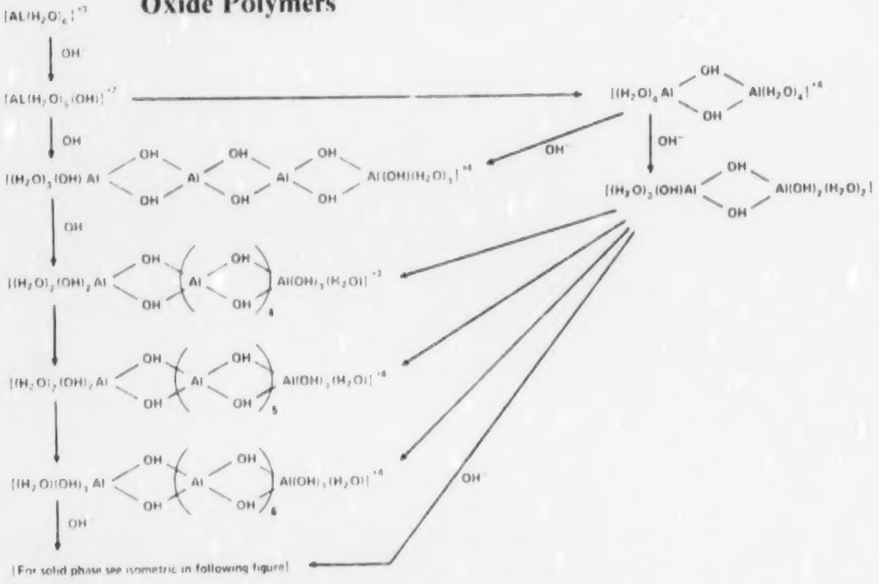

[Al(H2O)6]+3
OH⁻
[Al(H2O)5(OH)]+2
[(H2O)4 Al
OH
OH
Al(H2O)4]+4
OH⁻
[(H2O)3(OH) Al
Al
Al
Al(OH)(H2O)3]+4
OH⁻
[(H2O)3(OH)Al
Al(OH)2(H2O)2]
[(H2O)2(OH)2 Al
Al(OH)2(H2O)]+3
4
[(H2O)2(OH)2 Al
Al(OH)2(H2O)]+4
5
[(H2O)(OH)3 Al
Al(OH)3(H2O)]+4
6
OH⁻
[For solid phase see isometric in following figure]

Figure 14.

**Example of Complex which may exist in Precipitated Hydrous Aluminum Oxide Polymers**

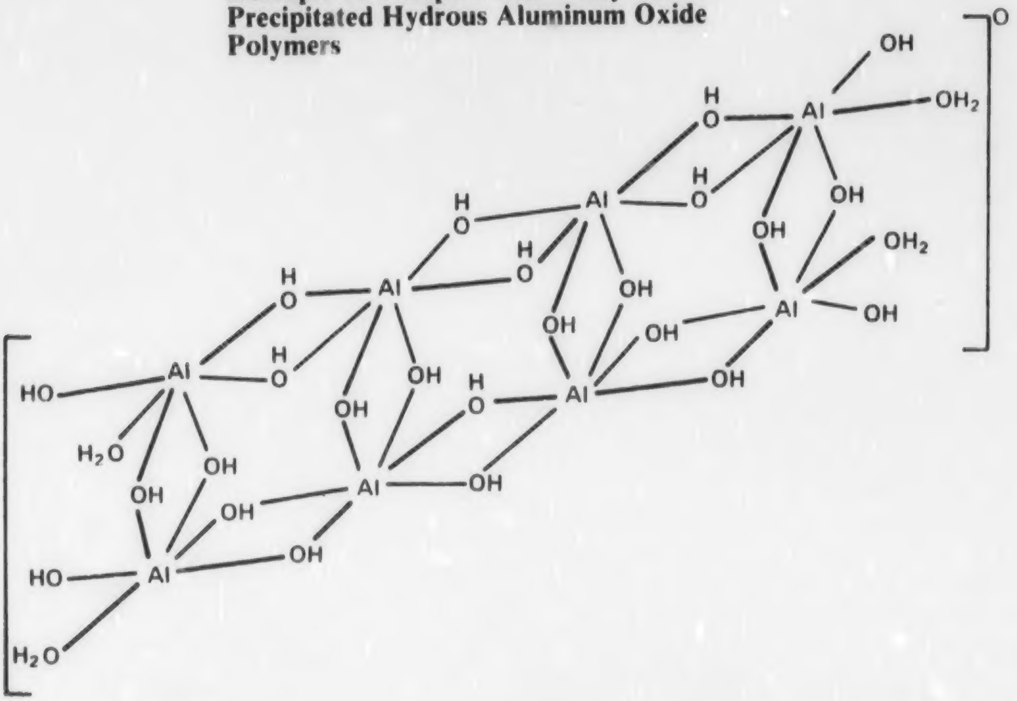

O
OH
H
O
Al
OH₂
H
O
OH
H
O
Al
OH
OH₂
H
O
H
O
Al
OH
Al
OH
OH
OH
Al
HO
H
O
OH
H
O
Al
OH
OH
H₂O
OH
OH
Al
OH
OH
OH
HO
Al
OH
H₂O

Figure 15.

**Equilibrium Compositions of Solutions in Contact with Al(OH)$_3$**

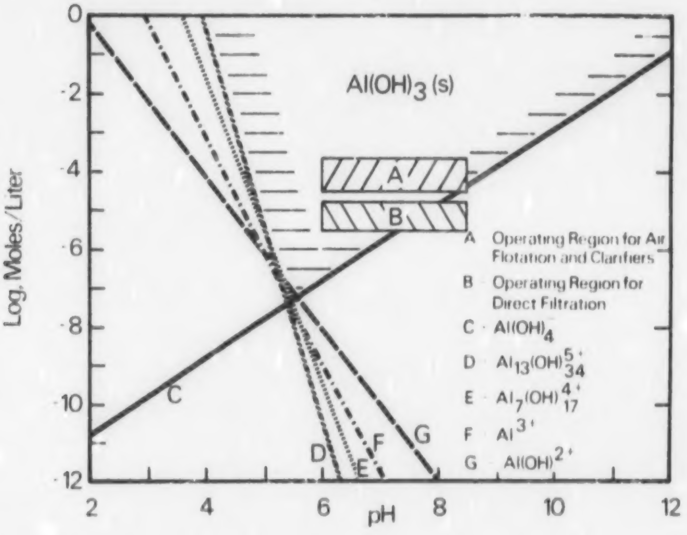


Figure 16.

**Equilibrium Compositions of Solutions in Contact with $Fe(OH)_3$**

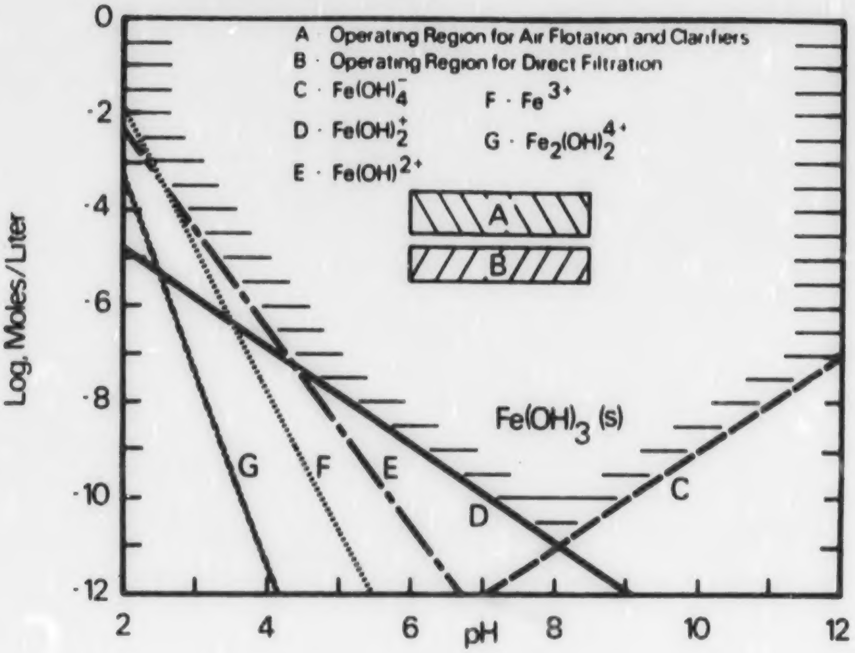


Figure 17.

**Zeta Potential of Colloidal Iron Hydroxide Solutions Plotted As A Function of pH**

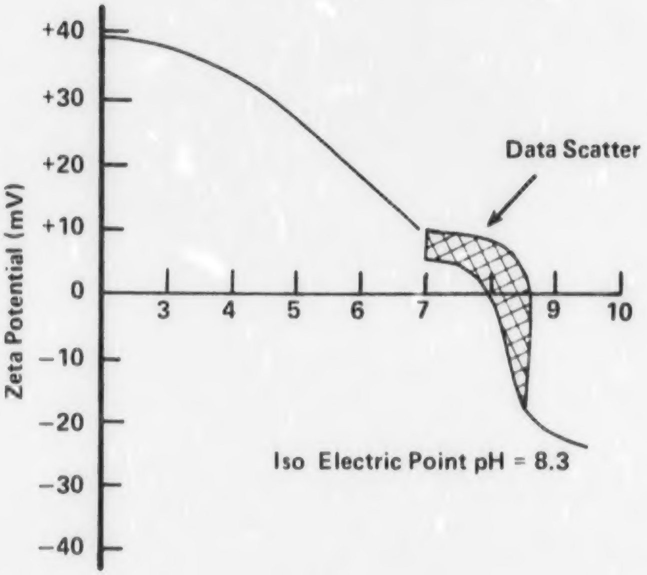


Figure 18.
**Zeta Potential — pH Plot for Aluminum Hydroxide**

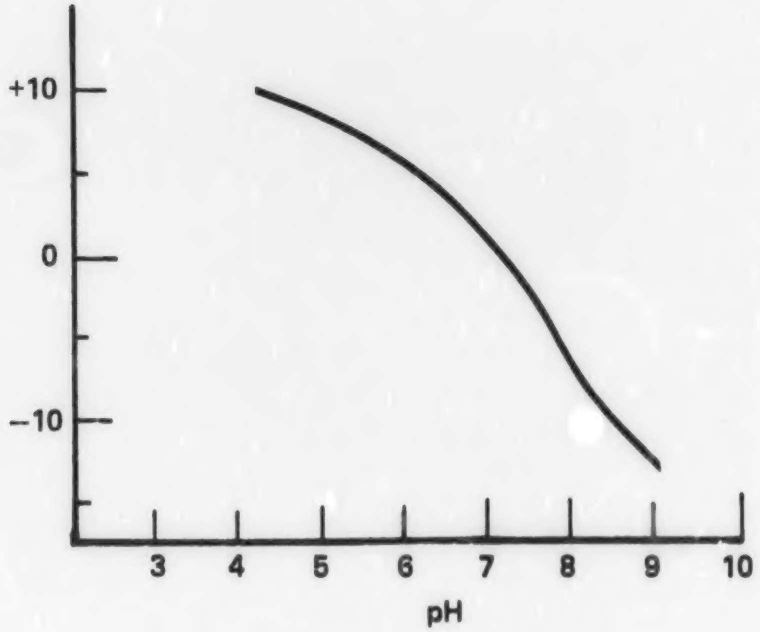
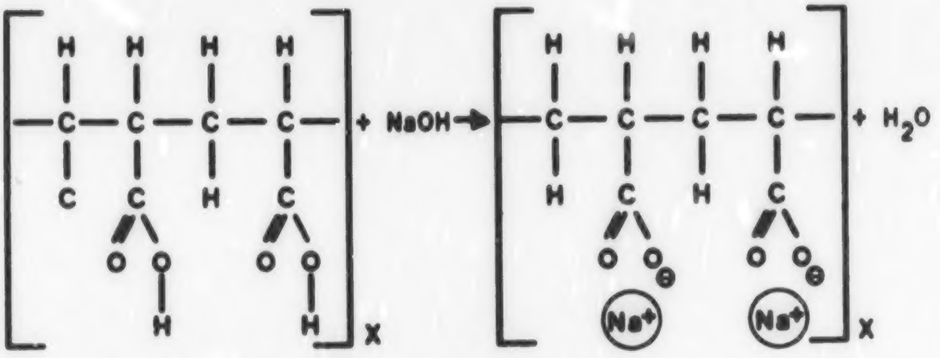


Figure 19.
**Dissociation Of Polyacrylic Acid By NaOH**



H
C
O
+ NaOH →
+ H2O
Na+
x

Figure 20.
Condition — Response Flow Schematic for Chemical Treatment of Waterborne Colloids

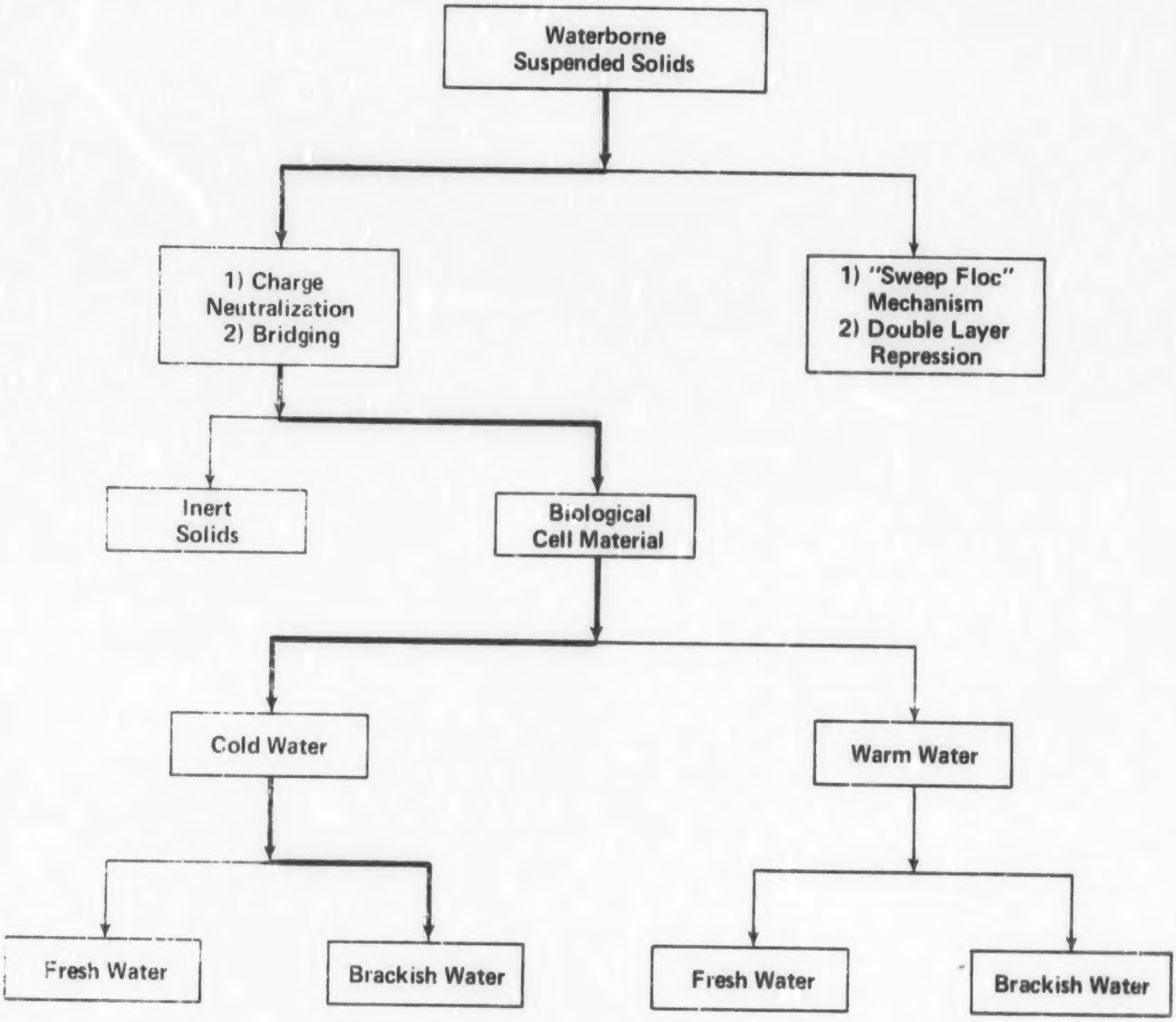

Waterborne Suspended Solids
1) Charge Neutralization
2) Bridging
1) "Sweep Floc" Mechanism
2) Double Layer Repression
Inert Solids
Biological Cell Material
Cold Water
Warm Water
Fresh Water
Brackish Water
Fresh Water
Brackish Water

Figure 21.

**Zeta Potential — Cationic Polyelectrolyte Titration Curves of API Separator Effluent**

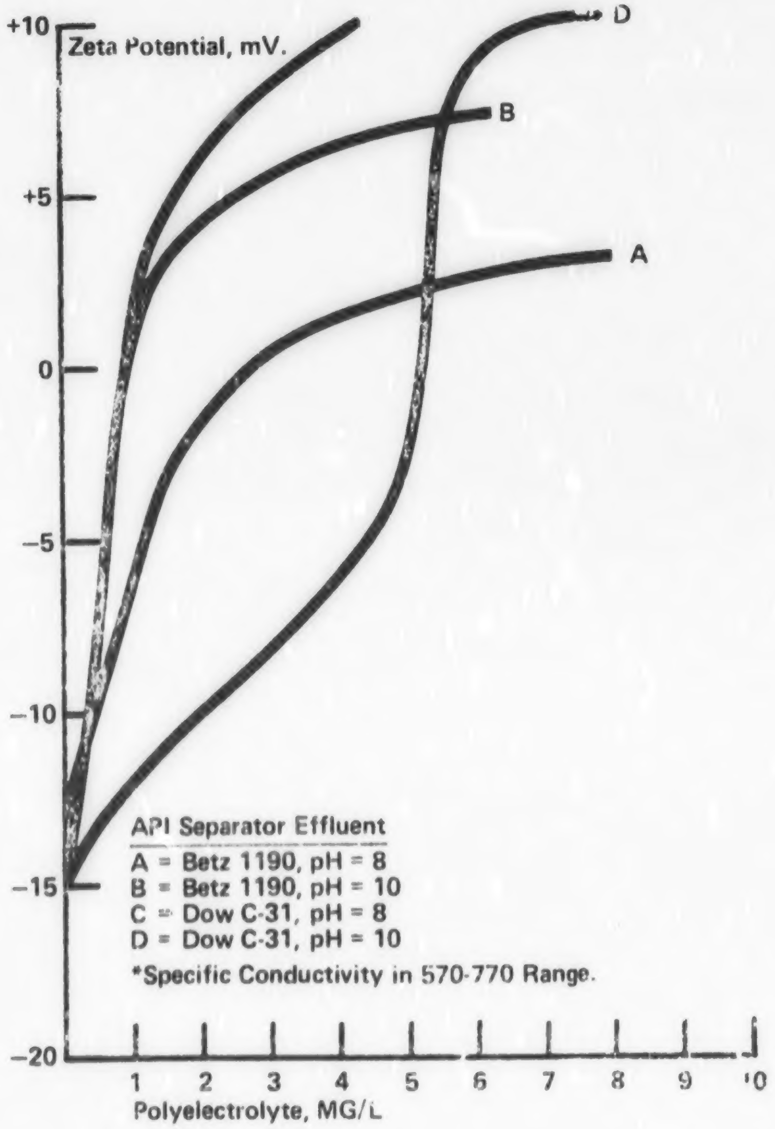


Figure 22.
Sensitivity of Dearborn 431 to pH and Phenol

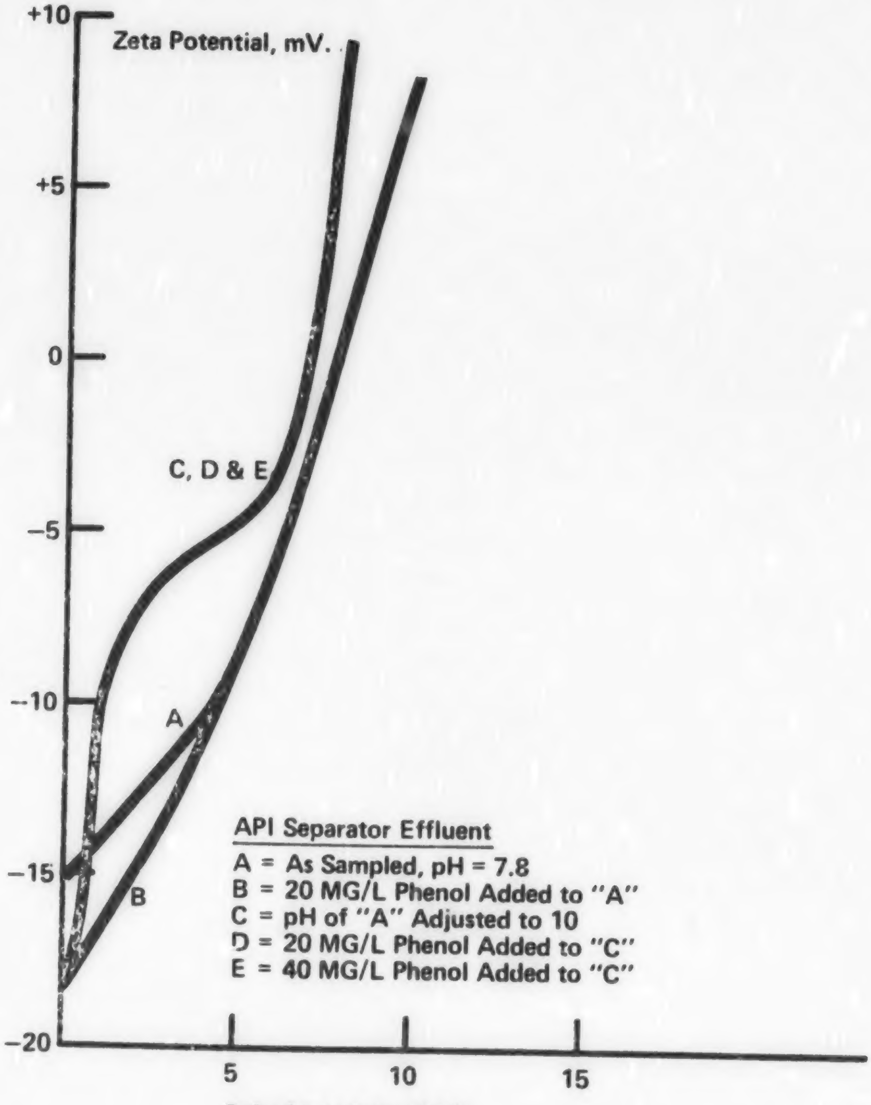


Figure 23.

**Sensitivity of Cyanamid 581 to pH and Phenol**

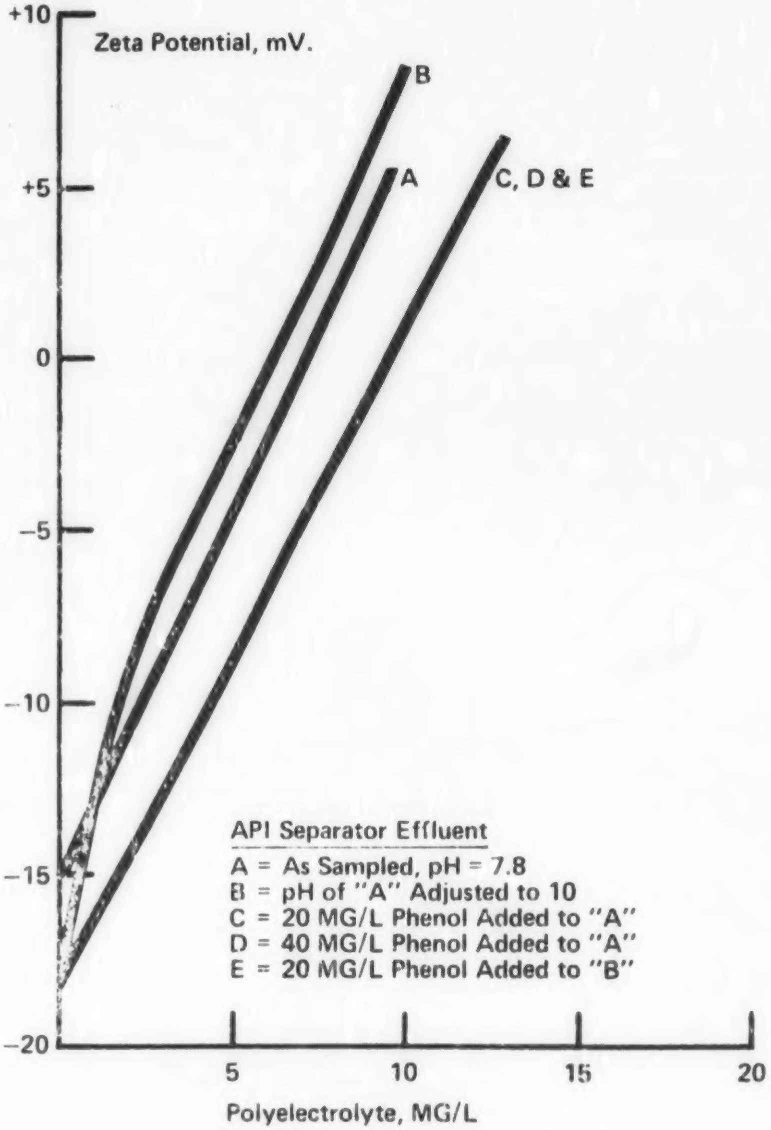


Figure 24.

Titration of Freshwater Aerated Lagoon Effluent with Cationics Zeta Potential, mV

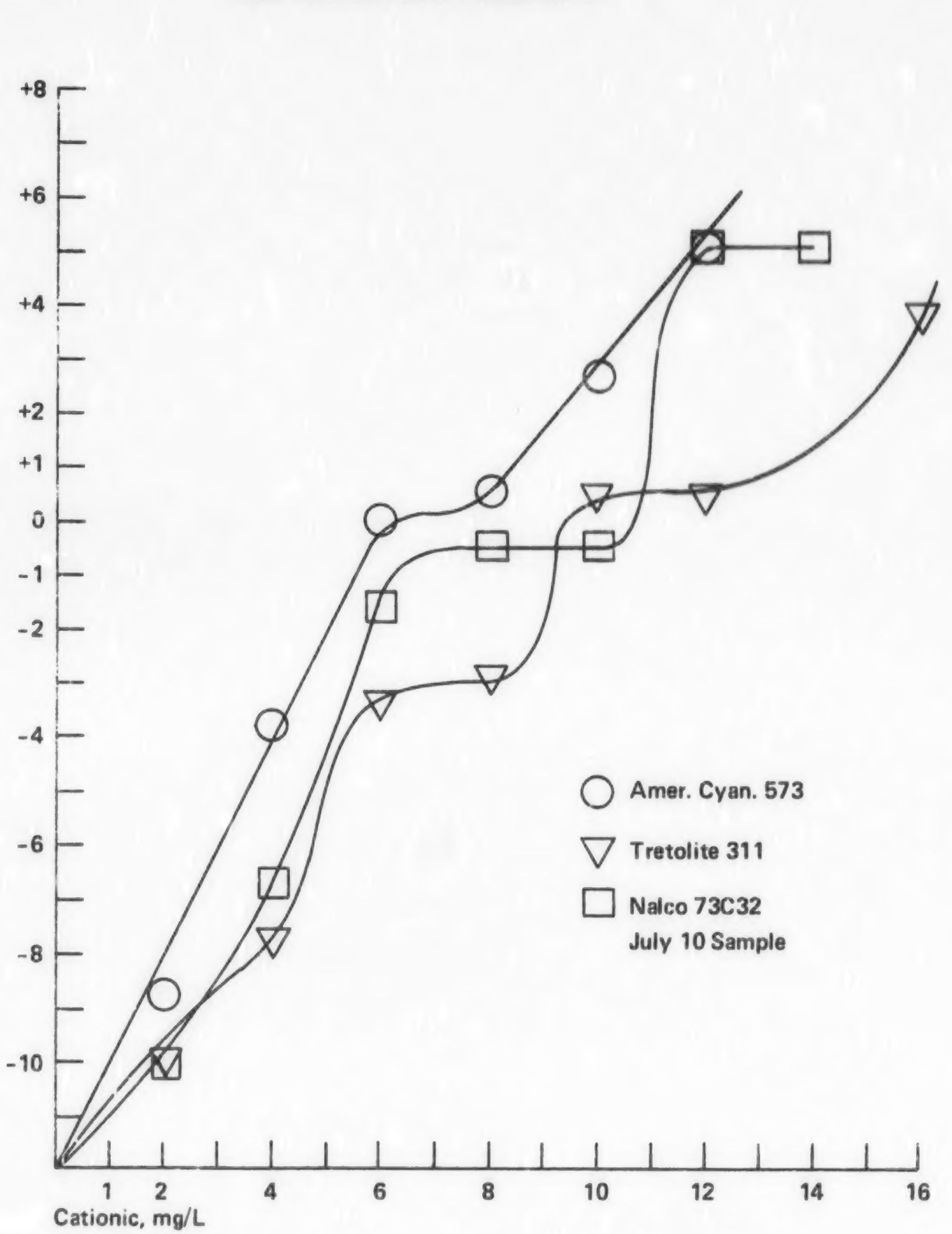


Figure 25.
Zeta Potential — Cationic Polyelectrolyte Titration Curves of Coke Fines in Hydraulic Decoking Waters (pH = 7.6)

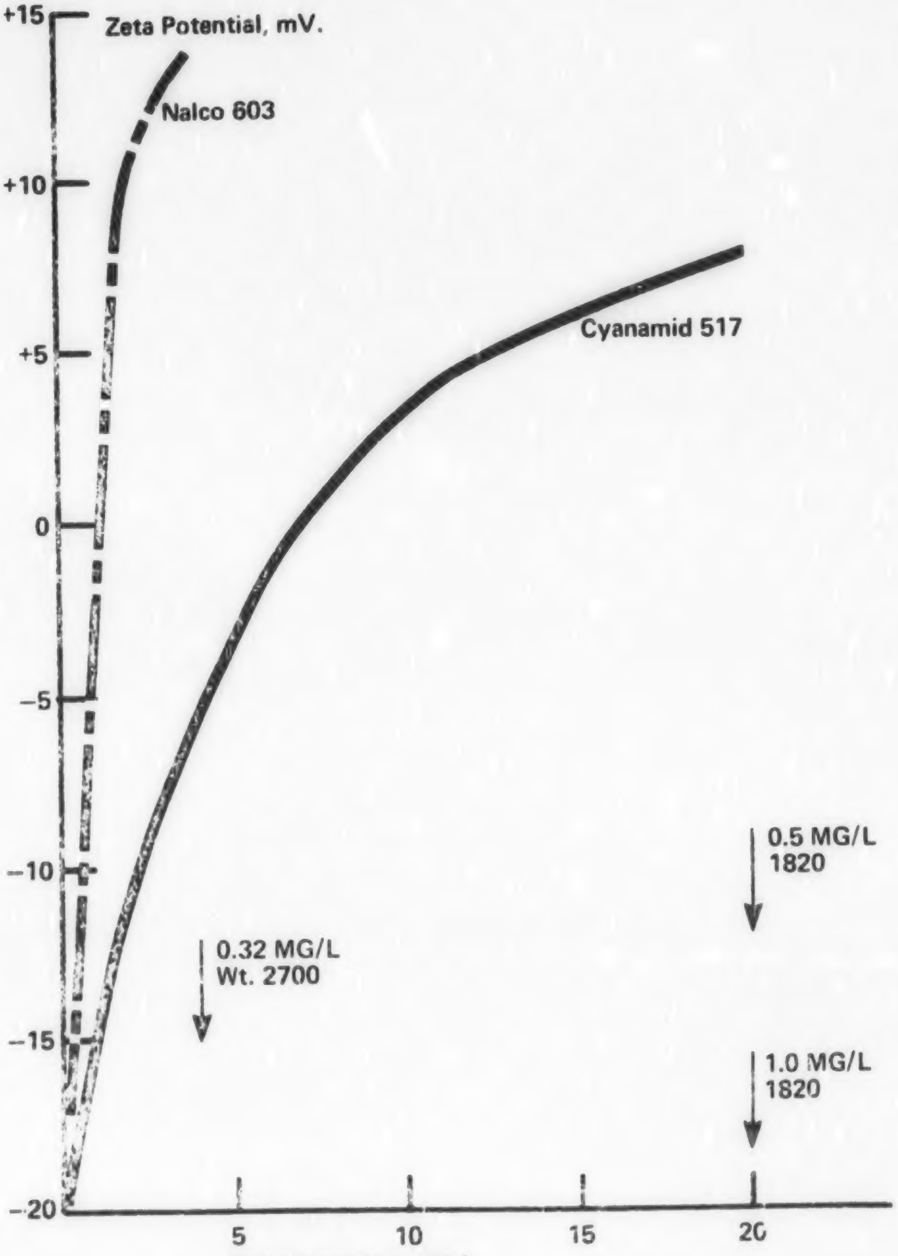
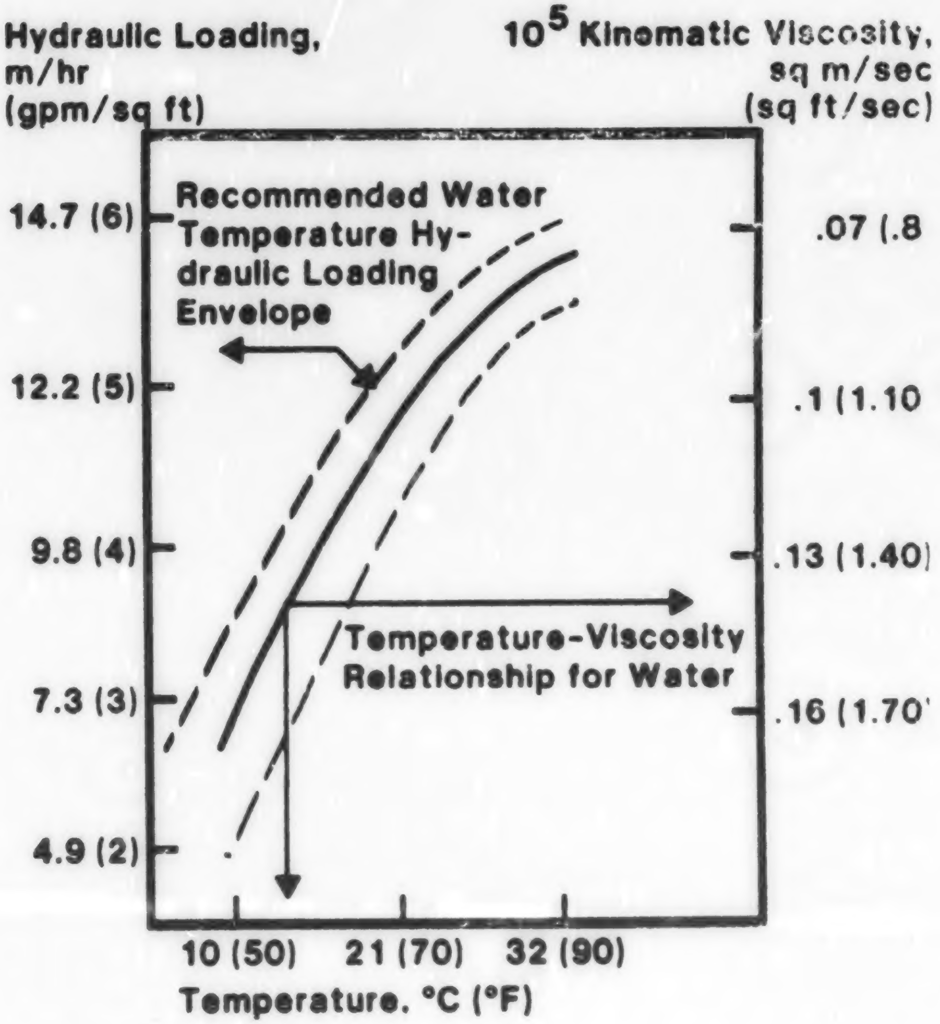


Figure 26.
Recommended Hydraulic Loading Rates as a Function of Water Temperatures and Showing the Correlation with Water Viscosity



# Combined Storm Overflow Treatment With SALA-HGMF® High Gradient Magnetic Filters

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**J. A. Oberteuffer**
Sala Magnetics, Inc.

*This work reported herein was performed in part under USEPA Contract Number 68-03-2218*

## Summary

Magnetite-seeded high gradient magnetic filtration is an exciting new technology which permits highly effective removal of $BOD_5$, COD, bacteria, color, turbidity and viruses from many types of polluted or contaminated waters. The theory and design of high gradient magnetic filters is presented and the application to two groups of polluted waters—combined storm overflow and raw sewage—is discussed in detail. The design of a large system is presented and compared with conventional methods in terms of efficiency and capital and operating costs, showing that this technology offers many advantages over conventional treatment methods.

## Introduction

High gradient magnetic filtration is a new physical treatment technique. High gradient magnetic filters use a matrix filter bed developed by Kolm[1] and a magnetic separator originally developed by Marston[2] for brightening kaolin clay. High gradient magnetic filtration has broad application in both mineral beneficiation and water treatment. Numerous metal ores may be beneficiated and industrial minerals purified by this technique. Water treatment applications are numerous and include the filtration of waters contaminated with nonmagnetic pollutants as well as the more obvious filtration of wastewaters containing magnetically susceptible particulates.

Water treatment applications are categorized as "direct filtration" and "indirect filtration" applications. In the former, the particulates to be removed are paramagnetic or ferromagnetic and are directly removed without additional chemical treatment. In direct filtration, the particulates to be removed are nonmagnetic and must be pretreated to render then filtrable by magnetic means.

Applications of direct filtration are in the treatment of steel making waters, metal finishing waters, boiler feed waters, and condensate polishing. These applications are reported in papers by Harland,[3] Oberteuffer,[4] and Marston[5].

Indirect filtration has been applied to industrial effluents such as those from paper and pulp mills, to sewage, to polluted river waters, to storm sewer overflow and drainage waters, and to the removal or concentration of viruses. As the particulates to be removed are nonmagnetic, it is necessary to render them magnetic so that they can be trapped on the magnetized filaments of the filter matrix. This is achieved by flocculating the contaminants around finely divided magnetic seed (magnetite) by the use of alum or other flocculating agents. Polyelectrolytes may be added to strengthen the flocs against physical disruption, allowing for rapid flow flux rates, and to increase filtration efficiency by increasing the size of the agglomerates and thus the chance that each particle will be bound to a seed particle, as well.

## Theory

### Background

The theory and design of high gradient magnetic filters is presented in review by Oberteuffer[6] and more specifically by Watson,[7] Luborsky[8] and others.[9-11] However, the fundamentals of operation and design may be understood from reviewing Figure 2-1, a schematic of a cyclic filter which also indicates the forces interacting to affect filtration effectiveness.

The solenoid electromagnet is surrounded by an iron return frame which serves to limit fringe fields and also adds to the uniformity of the magnetic field in the working volume of the filter. The canister, placed within the solenoid electromagnet, contains a filamentary ferromagnetic matrix or filter bed material which, when magnetized, forms the large number of very high gradients necessary for trapping and holding fine and even extremely weakly magnetic contaminants until the magnetic de-energized. The magnetic force ($F_m$) which attract these particles may be determined from the general equation

$$F_m = V\ M\ \text{grad}\ H \qquad (2)$$

where V is the particle volume, M is the particle magnetization (a function of magnetic susceptibility of the particle and magnetic field) and grad H, the magnetic field gradient. The magnetic field gradients developed in a high gradient magnetic filter range from 1000 to 10,000 kG/cm, or one to two orders of magnitude greater than those in conventional magnetic devices. These gradient forces are strong enough to pull particles to the matrix filaments against the competing forces of hydrodynamic drag and gravity which tend to push particles through the filter. The hydrodynamic drag force ($F_c$) is approximated by the expression

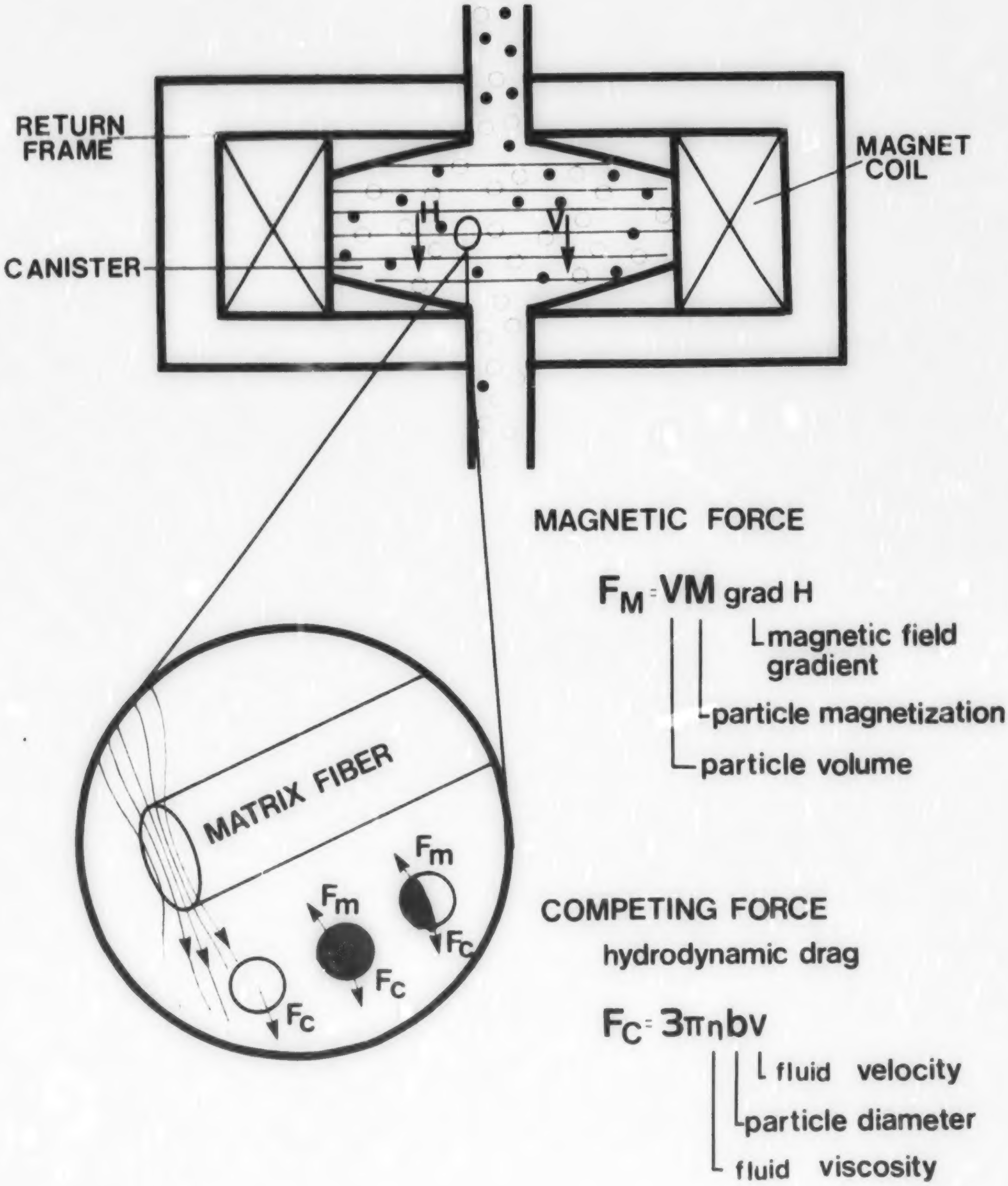
$$F_c = 3\,\pi\,\eta\,b\ v \qquad (2)$$

where $\eta$ is the fluid viscosity, b is the particle diameter and v is the fluid velocity.

### Magnetite-Seeded Water Treatment

The use of these magnetic filters is obvious when the particles to be removed have even low magnetic susceptibilities. However, their use in removing nonmagnetic contaminants is less obvious. In the treatment of storm sewer overflow, the contaminants to be removed are essentially nonmagnetic and it is necessary, therefore, to render them magnetically susceptible. This is achieved

Figure 2-1.
**Schematic High Gradient Magnetic Filter and Interactive Forces Influencing Filtration Efficiency**


RETURN FRAME
MAGNET COIL
CANISTER
H
V
MATRIX FIBER
Fm
Fc
MAGNETIC FORCE
FM = VM grad H
magnetic field gradient
particle magnetization
particle volume
COMPETING FORCE
hydrodynamic drag
FC = 3πηbv
fluid velocity
particle diameter
fluid viscosity

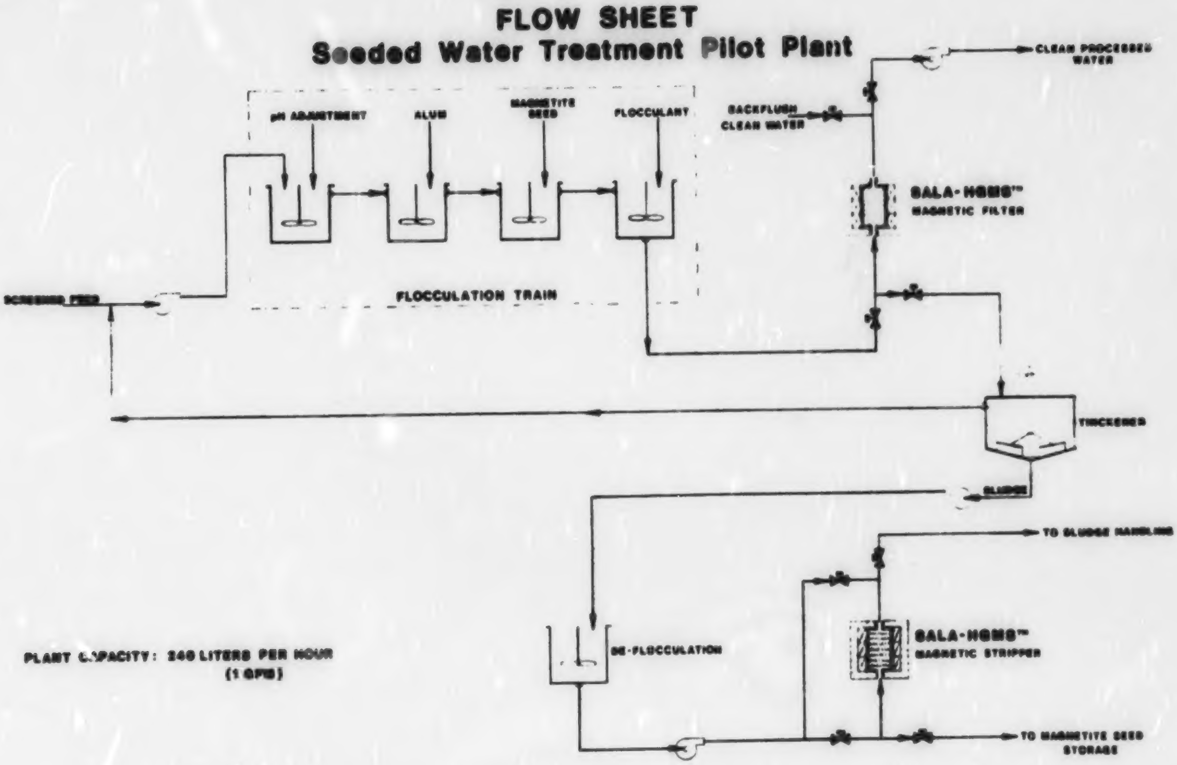


Figure 3-1.

FLOW SHEET
Seeded Water Treatment Pilot Plant

CLEAN PROCESSED WATER
pH ADJUSTMENT
ALUM
MAGNETITE SEED
FLOCCULANT
BACKFLUSH CLEAN WATER
SALA-HGMS™ MAGNETIC FILTER
SCREENED FEED
FLOCCULATION TRAIN
THICKENER
SLUDGE
TO SLUDGE HANDLING
PLANT CAPACITY: 240 LITERS PER HOUR (1 GPM)
DE-FLOCCULATION
SALA-HGMS™ MAGNETIC STRIPPER
TO MAGNETITE SEED STORAGE

by mixing finely ground magnetite into the fluid to be filtered and then adding coagulating and flocculating agents such as alum, iron sulfate or similar compounds to cause the precipitation or coagulation of contaminants around the magnetite seed. The chemical mechanisms of coagulation have been studied and described by deLatour[12] using artificially contaminated aqueous systems. Often a polyelectrolyte, a polar organic compound, is added to strengthen the flocs and prevent their disruption during the high velocity filtration process.

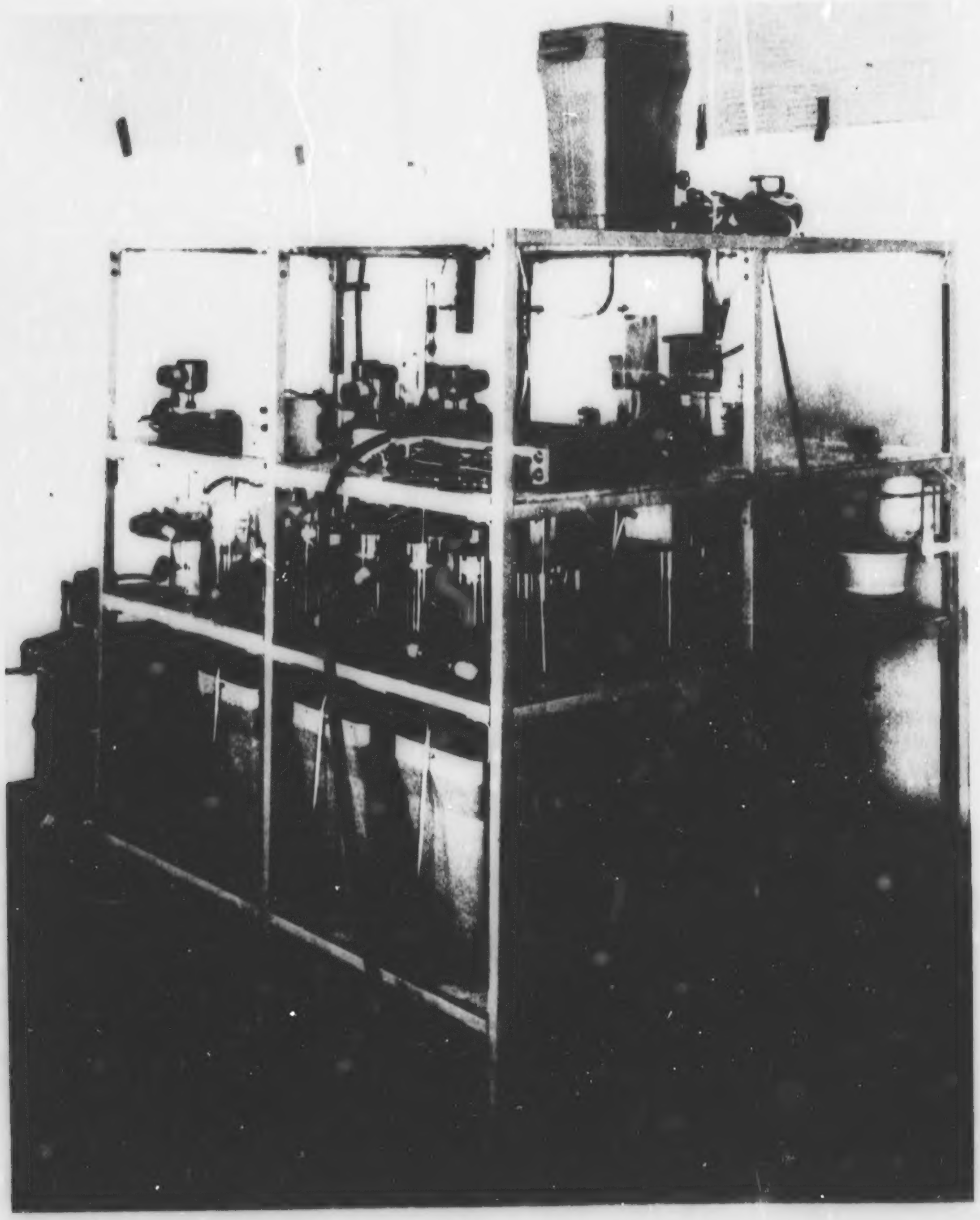
## SALA-HGMF® Magnetite Seeded Magnetic Filtration Pilot Plant

SALA has designed and constructed a 4-liter/min. continuous pilot plant[13] for studies of seed, flocculant and polyelectrolyte concentrations and mixing times as well as the standard high gradient magnetic separation parameters of flow velocity, field strength, matrix loading, and matrix structure. The pilot plant flow sheet is shown in Figure 3-1. This automatically operated pilot plant permits investigation of these filtration parameters and also is capable of producing sludge for preliminary studies on seed recovery and regeneration.

The applicability of the indirect filtration process for treating combined sewer overflow (CSO), storm water, secondary effluent, and dry weather sewage flow is now being investigated. The interest in this study is part of a broad EPA concern with controlling pollution of municipal waters and in treating those heavily contaminated waters feeding into natural water bodies. SALA is also involved in determining possible seeded water treatment applications in the paper mill industry in cooperation with NCASI.

Tests were carried out in the 4-liter/min. continuous pilot plant shown in Figure 3-2. As indicated in the flow sheet (Figure 3-1), the pilot plant contains a flocculation train in which all necessary chemical additions are made, a SALA-HGMF® magnetic filter and power supply, and a surge tank and thickener to handle the backflushed flocs that were trapped in the matrix bed. An automatic controller sequences the addition and mixing of chemicals, fluid movement from tank-to-tank, and the actual filtration and backwash cycles through the magnet. Untreated feed is pumped from the storage tank to the first residence tank where the feed is mixed with alum. The magnetite seeding material is added in a second, flash-mixing tank. Finally a polyelectrolyte is flash mixed into the stream to induce bonding among floc particles, bridging them together into larger agglomerates. The pH may be metered and controlled automatically.

Figure 3-2.
Four liter per minute Pilot Plant



The treated feed water is next drawn through the SALA-HGMF® high gradient magnetic filter by a filter pump located downstream from the magnet to avoid floc disruption. Once the filter cycle is completed, the filter pump and the magnet are shut off and the matrix is backflushed with high pressure water. The backflush water containing the flocs washed from the matrix filter bed enters a surge tank from which the integrated flow is fed to the thickener. Periodic chemical or detergent rinse cycles may also be necessary to ensure that no residual sludge buildup occurs on the matrix fibers.

The pilot plant system is so synchronized that concentrations of chemicals remain constant throughout the residence chain. The system is adjusted easily, moreover, to permit a wide range of individual chemical concentrations. As operation is continuous and automatic, matrix loading is much more simply tested than in the bench test system by merely lengthening the filtration time preceding backflush. Performance reliability may also be assessed by taking consecutive samples over many cycles run under the same set of operating conditions.

This 4-liter/min. pilot plant has provided all results presented and discussed herein. At present, this sytem is being modified, redesigned and installed into a mobile trailer unit under a USEPA contract so that tests may be performed on-site for the treatment of CSO and other polluted waters. The trailer unit will have a capacity of more than 20-liters/min with two magnetic filters in parallel to simulate a full-scale system's anticipated ability to phase in and out with multiple separators following surges in flow typically found in storm water applications. A more sophisticated process flow control system will be used and a chemical rinse system has been added that will prevent sludge buildups on the matrix fibers. Among the tests to be performed are those aimed at determining best flocculation techniques and system operational limits. Sludge characteristics will be evaluated for both disposal and alum/seed reuse possibilities. Matrix cleaning requirements will be determined as well as the most effective matrix fiber configuration and packing scheme. On-site testing will also attempt to demonstrate seeded water treatment adaptability to variability in flow volume in a "real" situation as the pilot plant will be run for the duration of at least one complete storm water activation.

## Pilot Plant Results

### Background

Initial operation of the 4-liter/min. pilot plant was based on an extensive series of parametric studies conducted at the Sala Magnetics laboratories. These studies established ranges of working conditions, including magnetic field strength, ratio of input contaminant levels to magnetite seed and alum concentrations, flow velocities through the matrix, mixing rates and residence times to form flocs of sufficient cohesiveness to remain intact when trapped in the filter.

### Pilot Tests

Pilot plant tests were conducted on several large samples of combined storm overflow (from Cottage Farm Chlorination and Detention Facility influent, Cambridge, Mass.), on raw sewage (from Deer Island Sewage Treatment Plant influent, Boston, Mass.), and on secondary effluent from a final clarifier overflow using the activated sludge process (Brockton, Mass. Sewage Treatment Plant). A bench type test was also performed on a sample of paper mill effluent (from International Paper Co., Ticonderoga, N.Y.). Detailed descriptions of these tests and the results obtained are presented below.

Experiments carried out on the pilot plant were designed to test independently the following parameters and their interactions: alum, polyelectrolyte and magnetite concentrations; pH; magnetic field strength; flow velocity; residence time; and matrix loading. Evaluation of results was based chiefly on the analyses done on feed and treated samples for suspended solids, apparent color and turbidity. Fecal and total coliform counts were also performed on many of the samples. Selected treated and untreated samples were analyzed for COD, $BOD_5$ and trace metals.

Since the character of the waste water used during this study was very different for each storm or sewage sample collected, a wide range of "type" of waste waters was encountered. CSO, of course, differs from raw sewage, secondary effluent, or paper mill effluent. But even CSO as observed at Cottage Farm fluctuates tremendously in solids loading, etc. The time of year, time of the day, the amount of recent rainfall, the source of water (rain, snow, snow melt) and the duration of the storm, all affect the composition of the CSO. Likewise, raw sewage effluent varies a great deal.

Table 4-I compares overall results obtained with CSO and raw sewage. These data should approximate the actual performance to be expected from an on-stream installation as a result of the wide range of CSO influent characteristics to be encountered and because of the practical reality that optimal running conditions cannot always be maintained in such an installation. It should be noted that even with such experimental fluctuations, the results were excellent.

Table 4-II contains summarized data collected in continuous pilot plant treatment of CSO over a six hour span. Included among these data are results from many tests run at non-optimal operating conditions as the goal of this study was to establish optimal parameter values. The curves shown in the section below are derived from the treatment of both CSO and raw sewage. Although chemical concentrations necessary to achieve quantitatively equal levels of purity or separation efficiency may differ from effluent to effluent, the relationships shown by these curves have been shown to be relevant for all waters polluted with suspended solids and treatable by the seeded water technique.

### Magnetic Parameters and their Interactions

*Magnetite Seed*

Magnetite seed is necessary to impart a magnetic property to the flocculated solids in the water, thus allowing for floc retention inside the magnetized matrix of SALA-HGMF® magnetic filters, minimum concentration of magnetite

Table 4-I

## Summary of Percent Removals for All Tests (Bench and Pilot Plant)

| | Suspended Solids | Apparent Color | Turbidity | Fecal Coliform | Total Coliform | BOD$_5$ |
|---|---|---|---|---|---|---|
| **CSO** | | | | | | |
| Average of all Samples Tested (% Removals) | 95 | 87 | 93 | 99.2 | 99.3 | >92 |
| Range Percent | 83-99.1 | 55-98 | 74-99 | 95-99.96 | 97-99.89 | >91-93 |
| (# of Tests) | (85) | (78) | (77) | (8) | (10) | (4) |
| **Raw Sewage** | | | | | | |
| Average of all Samples Tested (% Removals) | 91 | 82 | 88 | 99.4 | | |
| Range Percent | 70-93 | 74-94 | 81-91 | 98.7-99.6 | | |
| (# of Tests) | (30) | (30) | (30) | (7) | | |

Table 4-II

## Continuous Pilot Plant (6 Hour Run)

| CSO Collected On 3/17/76 | Suspended Solids (mg/ℓ) | Apparent Color (PCU) | Turbidity (FTU) | Fecal Coliform (cells/100 ml) | Total Coliform (cells/100 ml) | BOD$_5$ (mg/ℓ) | COD (mg/ℓ) |
|---|---|---|---|---|---|---|---|
| **Feed Average** | 460 | 650 | 230 | 3.6 x $10^7$ | 6.3 x $10^7$ | >79 | 410 |
| (# of Tests) | (3) | (3) | (3) | (4) | (4) | (2) | (2) |
| Range | 400-520 | 600-800 | 200-250 | 2-5 x 10 | 5.1-7 x $10^7$ | >75-83 | 395-425 |
| **Treated CSO**<br>Average | 28 | 85 | 19 | 5.3 x $10^4$ | 1.1 x $10^5$ | 6.0 | 106 |
| (# of Tests) | (42) | (42) | (42) | (6) | (6) | (4) | (5) |
| Range | 4.1-185 | 41-210 | 8-65 | 1.5-13 x $10^4$ | 0.70-2.2 x $10^5$ | 5.2-7.0 | 93-138 |
| **% Reductions** | | | | | | | |
| Average | 94% | 87% | 92% | 99.85% | 99.83% | >92% | 74% |
| Range | 60-99% | 68-94% | 72-97% | 99.64-99.96% | 99.65-99.88% | >91-93% | 66-77% |

**Test Conditions**

| | | | |
|---|---|---|---|
| Magnetic Field: | 0.1; 0.5; 1.0; 1.9 kG | Magnetite Conc.: | 200; 420; 500 mg/ℓ |
| Flow Velocity: | 56; 225 m/hr | pH: | natural 7.3 |
| Alum Conc.: | 50; 70; 100; 150; 200 mg/ℓ | Residence Time: | 3; 12 minutes |
| Polyelectrolyte Conc.: | 0; 0.1; 0.5; 1; 2; 2.5 mg/ℓ | | |

(about 100 mg/l for example) is needed for good removal. Above this value additional magnetite does not improve filtration efficiency significantly. For concentrations below about 100 mg/l, however removal percentages decrease indicating that insufficient magnetite seed is available as nuclei around which flocs may form.

*Matrix Loading and Seed to Solids Ratio*
An important parameter to consider when designing a system is matrix loading (the ratio of the weight of sludge held on the matrix in a single cycle to the weight of matrix material). The size of the magnet and the related system depends directly on the matrix volume needed to handle the expected flow at reasonable flow velocities with adequate filter cycle length. Thus that point in a prolonged cycle at which filtration efficiency drops below acceptable levels should be determined before a system is designed. This drop in efficiency of filtration usually occurs suddenly in the filter cycle and is called "breakthrough". The point at which breakthrough occurs in the filter cycle is dependent upon a number of factors, including total solids loading, flow rate, polyelectrolyte concentration, and seed-to-solids ratio.

Matrix loading tests performed by varying seed-to-solids ratios are of value in determining how much magnetite will be needed to attain an adequate duty cycle for practical application. As delay and flush cycles occupy only about 5 seconds for this size apparatus, a duty cycle of well over 99% can be achieved at a seed-to-solids ratio of about 1.5:1. The duty cycle can be extended even further for high seed-to-solids ratios. Thus, by varying the amount of magnetite put into the system, duty cycle length can be manipulated to a substantial extent.

When a closer look is taken at the physics and physical phenomena occurring at the site of capture (matrix disk surface) the explanation of the above described relationship becomes clear.

Were the materials being separated 100% highly magnetic in nature, the matrix volume (~ 93% void volume) would continue to load to capacity (clogging) with very little decrease in effluent quality. When the particles being trapped by the magnetic matrix have equal magnetic susceptibility, the net gradient present on the surface formed by their layering on the matrix decreases only very gradually with layer thickness, because each new layer of magnetic material concentrates the magnetic flux nearly as efficiently as the matrix fibers. In this case, the formation of additional layers is limited only by shearing forces created by the flow and irregularities in the layers themselves. This is not the case, however, when nonmagnetic suspended solids are a major portion of the solids held to the matrix. Here, the net force acting on a volume of solid particles (floc) is much lower because the net susceptibility of the agglomerate to the field is due only to the magnetite portion of the total mass. This has two effects on the magnetic separation; decreased filtration efficiency (some flocs may not have had enough magnetite incorporated within to be held by the magnetic gradient) and decreased capacity of the matrix before breakthrough (the point at which shear forces equal or exceed magnetic forces). Thus, the thicker the solids layer *or* the less (relatively) the magnetite concentration in the flocs, the shorter will be the effective filter cycle length.

**Magnetic Field Strength**
Like magnetite concentration, magnetic field strength has a rather straightforward relationship to filtration efficiency (Figure 4-1). For the high matrix loadings of the CSO of 3-17-76, a field of at least 0.5 kG was necessary to hold the seeded flocs. Almost total breakthrough occurred at 0.1 kG, indicating the all-or-none type response typically obtained with magnetic seeding techniques. Curves given show this relationship for suspended solids, turbidity and apparent color. Above 0.5 kG there appears to be little change in % removal with increased magnetic field strength at this flow rate (224 m/hr).

During surge flows, increased flow velocities through the SALA-HGMF® magnetic filter are necessary to accomodate the large volumes of water if reserve units are not available. Increased flow rate means larger shearing forces will be present within the system, especially within the matrix where drag forces are maximal. To overcome this added stress, the magnetic field must be increased to hold the magnetic flocs securely. In such cases, polyelectrolyte concentration may also have to be increased so that floc breakup will not occur. Seed-to-solids ratios used during surge flows must be considered because a higher proportion of magnetite may be required to hold the flocs in the magnetic matrix.

**Flow Velocity and Residence Time**
Flow velocity and residence time are also directly related to surge flow. As mentioned above, flow velocity through the magnetic matrix will increase with increasing influent surges (unless reserve systems are adequate to handle the increased flow). Also, if the flocculation mixing tanks are of fixed capacity, a large surge will result in a faster turnover of water and therefore a shorter mixing time.

In the present study it was found that a residence time of only three minutes was adequate for complete flocculation. Longer mixing times had no adverse effects on separation efficiency. Thus, this parameter is relatively insensitive to change and need not be controlled precisely.

Figures 4-2 and 4-3 show results from a series of tests on CSO to determine the maximum practical flow flux rate possible with a particular feed and seed-to-solids ratio. Other parameters were unchanged. These curves clearly show that as flow rate is increased, efficiency is decreased (slope of curves) and the effective cycle time is shortened (divergence of curves). Depending upon the water quality requirements and economies of the individual situation, different flow flux rates may be used. It is apparent from these curves that as the flow increases above 200 gpm/ft², the stronger shear forces disrupt the magnetically seeded flocs releasing some of the suspended solids from the magnetite.

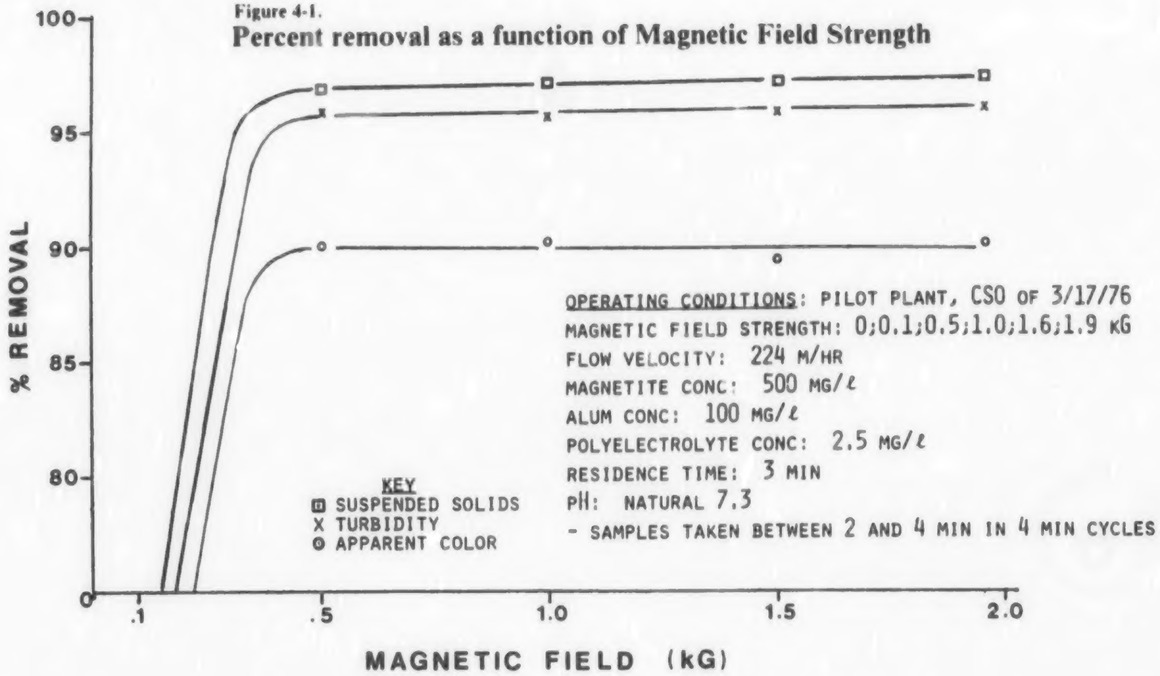


Figure 4-1.
Percent removal as a function of Magnetic Field Strength

OPERATING CONDITIONS: PILOT PLANT, CSO OF 3/17/76
MAGNETIC FIELD STRENGTH: 0;0.1;0.5;1.0;1.6;1.9 KG
FLOW VELOCITY: 224 M/HR
MAGNETITE CONC: 500 MG/ℓ
ALUM CONC: 100 MG/ℓ
POLYELECTROLYTE CONC: 2.5 MG/ℓ
RESIDENCE TIME: 3 MIN
PH: NATURAL 7.3
- SAMPLES TAKEN BETWEEN 2 AND 4 MIN IN 4 MIN CYCLES

Figures 4-2 and 4-3 indicate that a reasonable flow flux rate for standard operation (86 gpm $\text{ft}^2$) during test programs has been chosen. Any lower flow flux rate would increase treatment costs without providing a significant increase in efficiency. Faster flow flux rates show a fairly rapid decrease in separation efficiency for this set of conditions. Some improvement in efficiency of separation can probably be achieved for the higher flow flux rates by strengthening the flocs. This involves the use of additional polyelectrolyte and thus higher operational cost per gallon, but such costs might in some instances be offset by a reduction in capital expenditures for equipment necessary to handle the given maximum flow.

### Interacting Chemical Parameters

*Alum*

Alum $(Al_2SO_4)_3 \times 18\ H_2O$ was used as the principal coagulant in all tests performed. Both a reagent and commercial grade have been tried, but careful correlations have not yet been made. Alum concentration is a very important parameter for effective filtration, as without good flocs nonmagnetic particles will not be removed by the magnet. The key to efficient seeded high gradient magnetic filtration is, above all, to coagulate a high percentage of the solids around a magnetite nucleus. Once this is achieved, the flocs can be strengthened easily, if necessary, by an organic polyelectrolyte and removed by the high gradient magnetic filter.

Optimal alum coagulation is directly dependent upon a number of interrelated factors including pH, solids loading and character, and relative amounts and kinds of other flocculating agents used (polyelectrolyte in the present case). Optimum alum coagulation occurs at a slightly acid pH while polyelectrolyte flocculates best at around pH 8 for raw sewage or CSO. Thus, where tests have shown that both a coagulant (e.g. alum) and a floc-strengthening agent (e.g. polyelectrolyte) are necessary, a compromise must be made between the two pH extremes. Since results show that this compromise is not detrimental to filtration efficiency, it may in fact prove to be advantageous, since the pH of CSO and sewage is usually close to 7 and amenable to this combination of chemical flocculants. It is thought that pH adjustment should be minimal or might be eliminated altogether when these flocculants are used in the proper proportions. Except for certain tests devised specifically to determine pH effects, all tests in this study were made at natural pH. The excellent results obtained show that alum-polyelectrolyte flocculation works well at normally encountered waste water pH values. Feed water character also affects optimal alum concentration. Tests conducted without alum (and with polyelectrolyte) showed essentially no separation as flocs were very stringy and did not entrap significant amounts of the solids in the water. Tests with paper mill effluent have shown that true color removal with magnetic separation techniques is due entirely to alum precipitation of that color.

### Polyelectrolyte

Filtration efficiency seems to reach an optimal plateau above a concentration of

Figure 4-2.

## Flow Flux Rate versus Suspended Solids

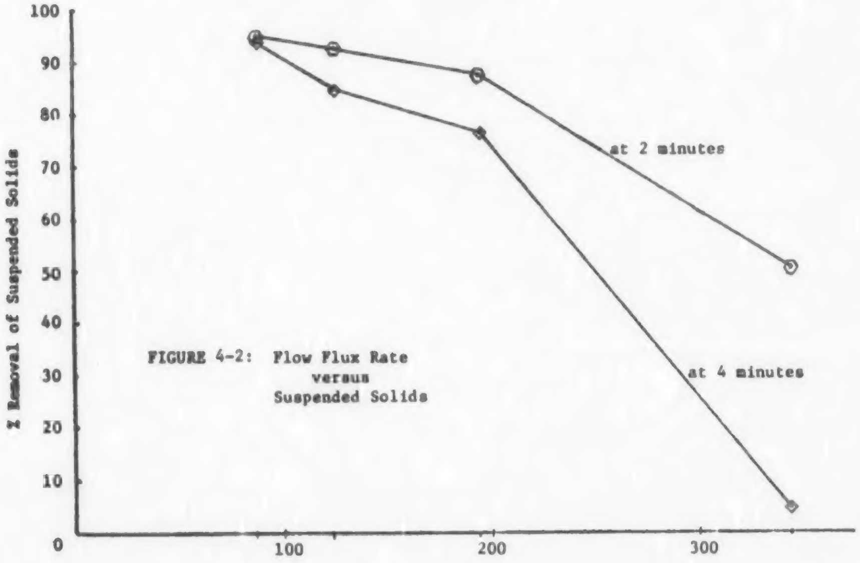
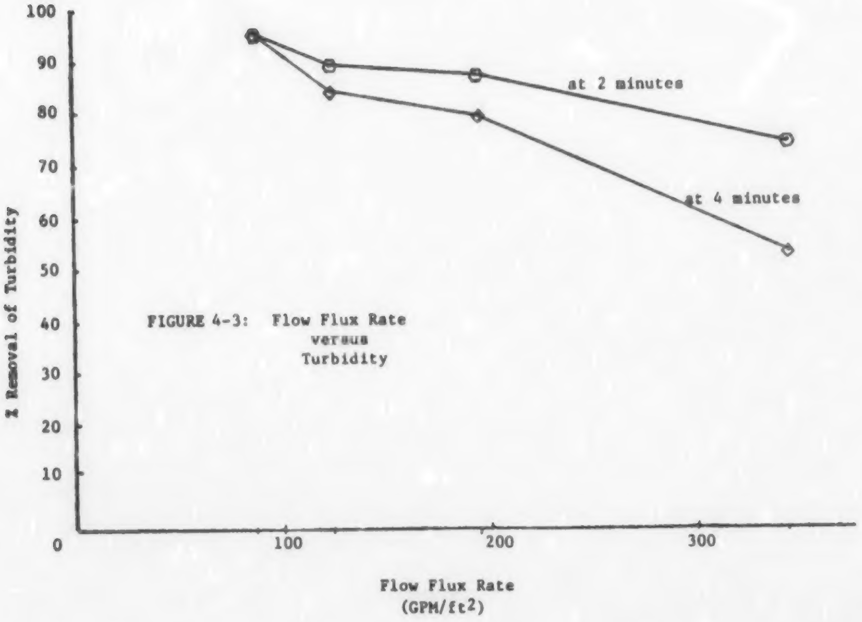


Figure 4-3.

## Flow Flux Rate versus Turbidity



about 0.5 mg/l polyelectrolyte. Below this minimum value, separation drops off rapidly. This is explained by hydrodynamic shearing forces, which break up the flocs inside the matrix when too little polyelectrolyte has been added. Earlier bench tests showed that at rather low flow velocities, less than 60 m/h, the curve for polyelectrolyte was essentially a straight line (i.e., polyelectrolyte was not needed at this flow rate as the shearing forces were below the threshold of floc disruption). Likewise higher concentrations of polyelectrolyte may be necessary at flow rates above the 224 m/h maximum flow velocity tested.

**pH**

As discussed above, pH plays an important role in the filtration effectiveness achieved using alum and polyelectrolyte as flocculants. As is expected, when there is relatively more polyelectrolyte present, optimal pH for filtration efficiency moves in the basic direction (towards pH 8) while, when relatively more alum is present, optimal pH moves in the opposite direction (towards pH 6). Other chemical factors present in the waste may also play a part, but the flocculant concentration ratios seem to be of primary importance in determining the preferred pH. While good flocculation was always achieved without pH adjustment, somewhat better filtration might have resulted from slight pH adjustments. However, the acceptable range of pH for good separation is wide enough to accomodate normal waste water fluctuations making continuous pH monitoring and adjustment unnecessary.

**Tests with Secondary Effluent**

A secondary effluent taken from the final clarifier of an activated sludge plant was treated using SALA's continuous pilot plant. Pilot plant operating conditions were based on the results of previous testing. Using these operating parameters, an average reduction of 88% was observed for suspended solids; an actual reduction from approximately 40 mg/l to 4-5 mg/l was achieved. In a second sample, solids were reduced from 26 mg/l to 1.6 mg/l, a 93% reduction. Apparent color and turbidity were reduced 71% and 85%, respectively, while fecal coliform levels were decreased by between 95 and 99%. Results for this polishing application would be improved by optimizing operating parameters.

**Paper Mill Effluent**

Bench tests were conducted on paper mill effluent to indicate the effectiveness of treating this water with a SALA-HGMF® magnetic filtration seeded water treatment system. The sample collected was aeration lagoon effluent from Ticonderoga, New York. Magnetite, alum and polyelectrolyte concentrations, pH and flow rates were varied over appropriate ranges in a parametric test. Although in absolute values, the purity of the water observed both before and after treatment was substantially lower than for CSO or raw sewage (∿15 times the solids loading) or for secondary effluent (∿ 30 times the solids loading) relative relationships between effluent quality and required chemical concentrations remained about the same. Optimal pH was near neutral as for CSO and raw sewage treatment and the practical limit for flow rate was ∿ 86 gpm/ft$^2$, as has been for other polluted waters. Summarized results for this paper mill effluent are given in Table 4-III below.

**Table 4-III**

| Analysis | Untreated | Treated | % Removal |
|---|---|---|---|
| $BOD_5$ (mg/l) | 60 | 2.8 | 95% |
| Total Suspended Solids (mg/l) | 1600 | 46 | 97% |
| Volatile Suspended Solids(mg/l) | 1035 | 26 | 97% |
| True Color (PCU) | 650 | 33 | 95% |

## Full Scale High Gradient Magnetic Filtration Treatment Facility

A 25 MGD integrated wet and dry weather high gradient magnetic filtration treatment plant has been designed using the operation parameters established in the 4-liter/min pilot studies. A schematic flow sheet for such a facility is given in Figure 5-1. Because of the excellent results obtained in the treatment of both CSO and raw sewage and the modular design of the high gradient magnetic filter system, a treatment facility capable of efficiently treating CSO during extreme flow variation might make the most effective use of this system. The feasibility of this application will be documented thoroughly in the on-site pilot tests and necessary design modifications made based on the new data.

The conceptual treatment plant is composed of five basic subsystems: 1) prescreening; 2) flocculation; 3) high gradient magnetic filtration; 4) dewatering; and 5) disinfection systems. The magnetic filter system incorporates a bank of magnetic filters arrayed in parallel. Other system components are conventional equipment included in typical sewage treatment plants. Table 5-I lists design parameters assumed in estimating costs.

**Costs**

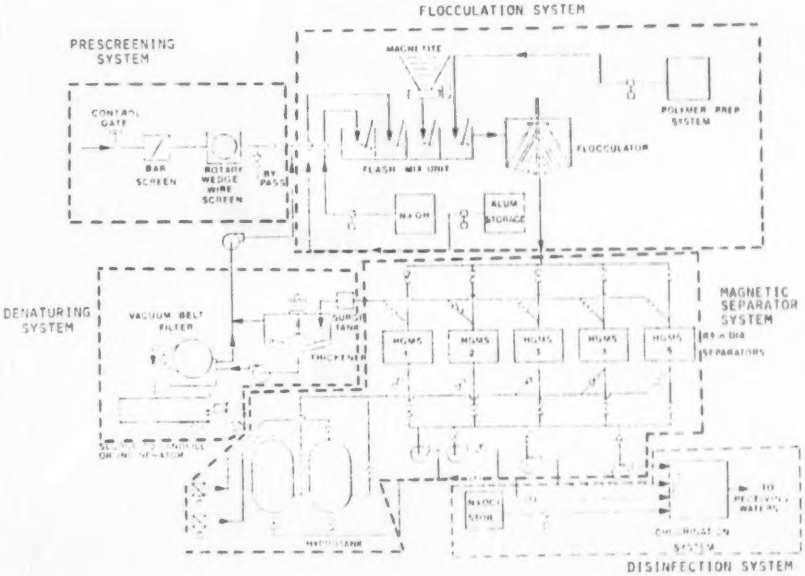
The estimated capital costs for the 25 MGD treatment plant shown schematically in Figure 5-1 are given in Table 5-II and include overdesign safety factors of 1.3 to 2.0 used in selection of equipment.

Capital costs include: control gate, coarse bar screen, grit chambers, rotary wedge wire screens, flash mixers, flocculators, flocculant feed systems, chemical storage facilities, high gradient magnetic filter systems, backflush systems, pumps, piping, conveyors, pH control, chlorination system, physical plant, land, instrumentation, and programmable process control system.

**Table 5-I**

| | Design Values |
|---|---|
| Magnetic field strength | 1.5 kG |
| Flow velocity in matrix | 245 m/hr (100 gpm/ft$^2$) |
| Maximum flow capacity @ 100 gpm/ft$^2$ flow velocity | 1.18 m$^3$/sec (25 mgd) |
| Nominal capacity | 0.60$^3$/sec (12.5 mgd) |
| Backflush flow rate | 0.95 m$^3$/sec |
| Flow rate/magnetic filter @ maximum capacity, 100 gpm/ft$^2$ flow velocity, and 90% duty cycle | 12.7 m$^3$/min (3.4 x 10$^3$ gal/MIN) |
| Average influent suspended solids | 300 mg/ℓ |
| Magnetite concentration | 300 mg/ℓ |
| Alum concentration | 100 mg/ℓ |
| Polyelectrolyte concentration | 1.0 mg/ℓ |
| Pumping head for filter pumps | 7.6 m (25 ft) |
| "G" factor for flash mixer | 300/sec |
| "G" factor for flocculators | 100/sec |

**Figure 5-1.**
**25 MGD SALA-HGMF® Integrated Wet and Dry Weather Combined Sewer Treatment Facility**


FLOCCULATION SYSTEM
PRESCREENING SYSTEM
CONTROL GATE
BAR SCREEN
ROTARY WEDGE WIRE SCREEN
BY PASS
MAGNETITE
POLYMER PREP SYSTEM
FLASH MIX UNIT
FLOCCULATOR
NAOH
ALUM STORAGE
DENATURING SYSTEM
VACUUM BELT FILTER
SURGE TANK
THICKENER
MAGNETIC SEPARATOR SYSTEM
HGMS 1
HGMS 2
HGMS 3
HGMS 4
HGMS 5
SEPARATORS
SLUDGE TO LANDFILL OR INCINERATOR
HYDROTANK
NAOCl STOR
TO RECEIVING WATERS
CHLORINATION SYSTEM
DISINFECTION SYSTEM

Costs of a pH adjustment system are included, although tests performed so far indicate there is little need for such a system. Also included are costs for a conventional chlorination facility. It is assumed that sludge generated in this facility would be shipped to incineration, landfill, or disposal facilities at a larger plant. Evaluation of sludge characteristics would indicate the best disposal means. On-site pilot tests may indicate modification of the sludge disposal system and provide the basic information for design of seed recovery and reuse systems.

Installation costs were based on estimates from both equipment suppliers and from the Chemical Engineer's Handbook.[14]

**Operation and Maintenance**

Estimated operation and maintenance costs presented in Table 5-III are based on the operating conditions listed in Table 5-I. The maintenance costs are based on annual operation at 50% capacity. Chemical costs for pH control are not included, since pH adjustment has proven unnecessary thus far. Similarly, the operating costs for the final chlorination step were not included due to the lack of effluent chlorine demand data.

Operator labor is based on 24-hour-a-day monitoring of the facility. In addition, an 8 hour shift is included for routine labor such as lubrication, cleaning bar and screening equipment, etc. The operator labor figure is considered conservative as the plant is designed for automatic operation.

The electrical costs breakdown (Table 5-IV) shows that the power consumption by the electromagnetic coils in SALA-HGMF® magnetic filters is relatively small in comparison with the power consumed by other process equipment. For operation at a 1.5 kG magnetic field, the magnetic filters consume only 16% of the total power required for the system.

An evaluation of the sludge handling costs is difficult due to the many considerations necessary. These considerations are economic, ecological and legal.

Table 5-II

## 25 MGD Integrated Wet and Dry Weather Flow Treatment Facility*

| **System** | **Capital Cost** |
|---|---|
| Prescreening | $ 132,000 |
| Floc Train and Chemical Feeding and Storage | 293,900 |
| Thickening and Dewatering Equipment | 218,250 |
| Backflush System | 169,500 |
| High Gradient Magnetic Filters (5 @ $165,600 ea.) | 828,000 |
| Pumps, Filter | 47,300 |
| Chlorination System | 42,250 |
| Process Control | 108,000 |
| Miscellaneous | 30,000 |
| Physical Plant | 110,000 |
| Installation Costs not Included in Above | 229,600 |
| | $2,208,800 |
| Construction Contingency 10% | 220,800 |
| | $2,429,600 |
| Engineering and Administration 10% | 243,000 |
| **Total Capital Cost** | **$2,672,600** |

**ENR = 2300*

## Table 5-III

## Operation and Maintenance Costs

| **Chemicals** | **$/1000 gal** | **$/yr (at 12.5 mgd)** |
|---|---|---|
| Alum @ $0.132/kg<br>100 mg/ℓ | 0.050 | $ 228,000 |
| Magnetite @ $0.022/kg<br>300 mg/ℓ (does not include freight charges) | 0.025 | 114,000 |
| Polyelectrolyte $3.10/kg | 0.012 | 55,000 |
| Total Chemical Costs | 0.087 | $ 397,000 |
| **Operator Labor** | | |
| 32 Man-hours/day @ $10/hr | 0.026 | 119,000 |
| **Maintenance** | | |
| Mechanical Equipment and physical plant (3% of equipment costs) | 0.012 | 55,000 |
| Electrical, Instrumentation and Piping (2% of equipment costs) | 0.002 | 9,000 |
| Total Labor and Maintenance | 0.040 | $ 183,000 |
| **Electrical** | | |
| @ $0.020/kWh<br>SALA-HGMF® Magnetic filters 1.5 kG require 85 kWh; other equipment 440 kWh | 0.010 | 46,000 |
| **Total Operations and Maintenance Costs** | **0.137** | **$ 626,000** |

Table 5-IV

## Power Consumption

| | |
|---|---|
| SALA-HGMF® Magnetic Filters 1.5 kG | 85 kWh |
| Flash Mixer Units (3) | 135 |
| Flocculators | 52 |
| Air Compressor @ 70% duty cycle | 35 |
| Vacuum Station | 48 |
| Filter Pump | 130 |
| Miscellaneous Consumption | 40 |
| **Total** | 525 kWh |

*SALA-HGMF® magnetic filters use approximately 16% of total power consumed.*

For many applications, especially those involving low solids loading, the magnetite seed costs are small compared with other processing costs and thus a recycle step may not be economically justified. Ecological consideration such as improved land-fill qualities resulting from very dense sludge may favor the seed discard option. Because of these considerations, seed discard may not always be the most expensive choice. Seed recycle might be advantageous for some large scale, continuous-flow treatment facilities. In such cases, additional capital expenditures might be justified in order to minimize operational costs.

Determination of the characteristics of the sludges generated by seeded high gradient magnetic filtration will indicate whether recycle of seed or seed-discard is most economical in a specific case.

## Comparison of High Gradient Magnetic Filter Systems to Conventional Treatment Methods

The comparison of high gradient magnetic filtration to conventional processes has been divided into separate comparisons for CSO and for sewage treatment systems. This has been done because most conventional systems do not perform as well in treating CSO as they do in treating dry weather flows. The extreme variations in flow and rapid change in influent character make conventional treatment processes inadequate for CSO treatment.

**Performance Advantages**
The performance of high gradient magnetic filters in removal of suspended solids, COD, $BOD_5$, and coliform bacteria is excellent in comparison with other processes. Tables 6-I and 6-II compare high gradient magnetic filtration to the most commonly used conventional treatment systems.

High gradient magnetic filter performance generally exceeds that of all other systems. Single stage treatment not only attains removal efficiencies exceeding those of conventional treatment, but, in addition, significantly reduces the levels of phosphates, heavy metals (Table 6-III) and virus in waste waters.

High gradient magnetic filtration for CSO treatment compares favorably with some tertiary level physical-cheminal treatments. Tables 6-I and 6-II also compare costs of high gradient magnetic filtration with costs for several alternate processes under evaluation of CSO and sewage treatment. The capital cost for a high gradient magnetic filtration integrated wet and dry weather flow facility is $107,000/MGD as compared to $168,000/MGD for a comparable physical-chemical treatment facility, and $73,000/MGD for a dual media filtration plant using polyelectrolyte.

Operation and maintenance costs are $0.137/1000 gallons for high gradient magnetic filtration, $0.187/1000 gallons for comparable physical-chemical treatment, and $0.169/1000 gallons for dual media filtration with polyelectrolyte.

Table 6-II compares high gradient magnetic filtration with several conventional sewage treatment processes. The cost of high gradient magnetic filtration also compares favorably with the cost of conventional raw sewage treatment.

**Other Advantages**
The economic value of reserve capacity is rather difficult to estimate. Systems employing high gradient magnetic filters can increase capacity simultaneously in two ways. One method is to increase flow velocity while simultaneously increasing magnetic field, and the other is to bring additional magnetic filters into operation. Since conventional systems do not have this flexibility, this consideration in particular makes high gradient magnetic filtration, where an array of filters are used in parallel, an attractive process for CSO treatment where handling of surge flow has been a problem.

Other advantages may occur due to the nature of the sludge produced. Because of the magnetite seed in the flocs, the sludge generated is much denser (approximately 20-30% solids by weight) than that produced in conventional waste water treatment systems. The mass of the relatively heavy magnetite acts to reduce the sludge water content.

Cost savings may be realized from reduced thickener and dewatering equipment size and better land-fill properties.

Table 6-I

## Comparison of CSO Treatment Processes*

| Treatment Process | Suspended Solids | % Removal Total BOD$_5$ | Coliform Bacteria | Capital Costs** 25 MGD | Operation and Maintenance** $/1000 gal |
|---|---|---|---|---|---|
| High Gradient Magnetic Filtration | 92-98 | 90-98 | 99-99.99 | 2,672,600 | $ 0.137 |
| Physical Chemical Treatment*** | 99 | 94 | 99 | 4,190,000 | 0.187 |
| Dual Media Filtration with Polyelectrolyte | 36-92 | 66-79 | -- | 1,817,000 | 0.169 |
| Rotating Biological Contactor | 70 | 54 | -- | 862,500 | 0.053 |
| Contact Stabilization | 92 | 83 | 83 | 2,251,100 | 0.058 |
| High Rate Trickling Filtration | 65 | 65 | 83 | 2,251,100 | 0.058 |
| High Rate Trickling Filtration | 65 | 65 | 83 | 2,275,600 | 0.073 |
| Dissolved Air Flotation with Fine Screening | 56-77 | 41-57 | 99 | 968,300 | 0.079 |
| Microstrainers | 70 | 50 | -- | 325,500 | 0.0023 |

* *Reference 8*

** *Since operating costs from "Urban Stormwater Management and Technology: An Assessment" are expressed in 1974, January 8, these figures have been adjusted by +20% to effect a fair comparison to high gradient magnetic filtration. Capital costs are adjusted to ENR = 2300.*

*** *Albany, N.Y. Pilot Plant (Ref. 3)*

Table 6-II

## Comparison Between High Gradient Magnetic Filtration and Other Sewage Treatment Processes*

| Treatment Process | Suspended Solids | % Removal COD | Coliform Bacteria | Capital Costs** 25 MGD | Operation and Maintenance** $/1000 gal |
|---|---|---|---|---|---|
| High Gradient Magnetic Filtration | 88-95 | 60-75 | 99-99.9 | $ 2,672,600 | $ 0.137 |
| Chemical Clarification | 60 | -- | -- | 1,522,500 | -- |
| Activated Sludge Treatment | 55-95 | 70-80 | 90-98 | 11,132,000 | 0.085 |
| Physical Chemical Treatment | 99 | 80 | 99+ | 4,190,000 | 0.187 |

* *Fair, G.M., Geyer, J.C. and Okun, D.A.,* Water Purification and Water Treatment and Disposal, *Vol. 2, John Wiley & Sons, New York, 1968, pp. 21-72*

** *Since operating costs from "Urban Stormwater Management and Technology: An Assessment" are expressed in 1974, January 8, these figures have been adjusted by +20% to effect a fair comparison to high gradient magnetic filtration. Capital costs are adjusted to ENR = 2300.*

Table 6-III

### Heavy Metals Removal

| Metal | Average % Reduction (Range) |
|---|---|
| Cd | > 43% |
| Cr | > 41% |
| Cu | 53% |
| Pb | (0-67%) |
| Hg | > 71% |
| Ni | (0-67%) |
| Zn | 84% |

A further advantage of high gradient magnetic filtration system is its comparatively small land use when building a new system and its configurational flexibility when updating an existing facility. Small land use is achievable because of the very high rates of filtration. The 25 MGD system described above would, for example, occupy only 0.35 acres (0.14 hectare). In regions where land is scarce and real estate values are high, this could result in considerable savings. In any situation the ecological advantages of a small system are numerous.

In existing plants, the magnetic filters can be arranged in such a way that space is used efficiently, perhaps preventing the need for additional land acquisition and facility construction.

## Conclusions

The preceding sections have detailed the theory of high gradient magnetic filtration and discussed its application to one group of filtration problems — the treatment of combined storm overflow and of sewage using magnetite seeding.

Besides the excellent removal of total and volatile suspended solids, fecal and total coliform bacteria, true and apparent color, turbidity and BOD$_5$, the SALA seeded water treatment technique has been shown to remove nearly 100% of all viruses,[15] and substantial amounts of COD (~75%), trace metals[16] such as zinc, chromium, lead and copper, phosphates,[17] and algae.[18]

The seeded water filtration process is a simple one involving well-known flocculation procedures and a simple highly effective easily maintained filter to remove contaminants from the effluent stream. No pH alteration seems necessary, although incoming solids loadings and flow rates should be monitored continuously to maintain optimal chemical concentrations. The system handles high flow rates and requires comparatively little land use for this reason. These factors, combined with excellent performance and competitive costs make magnetite-seeded high gradient magnetic filtration an exciting new technology for the treatment of many types of polluted or contaminated waters.

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# Use of Floatation for Waste Water Treatment

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The problem of water basins protection against contamination with industrial and municipal wastes has acquired primary importance. The existing methods and traditional schemes of waste water treatment do not always provide the required extent of contaminant removal. In this connection investigations are conducted on elaborating new methods and facilities for treatment of various kinds of waste water and improving the existing ones.

It is floatation that is considered to be one of the perspective methods used to remove suspended matter from water, including finely dispersed impurities. This method of treatment, based on separation of contaminants from liquid by means of floating up air or gas bubbles, is widely used in industry and municipal services.

Floatation as a method of contaminant removal is used at the following stages of waste liquid treatment:

- local treatment of wastes at enterprises and utilization of valuable products;
- water preparation for biological treatment;
- separation of sludge mixtures in aeration tanks, consolidation of excessive sludge and waste water sediments;
- final treatment of biochemically treated waste water.

It is quite reasonable to use floatation methods for treatment of waste water contaminated with oil wastes, oil-processing products, fats, resins, latexes, organic synthesis products, surface-active agents and dyestuffs. As compared to waste water treatment by way of settling, the floatation methods are more efficient especially in cases when the rate of particles settling is less than 0.1 m/sec, or when it is necessary to remove suspended matter from liquid containing considerable amount of dissolved gases etc.

The process of waste water treatment by floatation method is 4-6 times faster than that of settling, the efficiency of contaminant removal being the same.

The possibility of removing finely dispersed suspended matter from liquid by way of floatation allows the latter to compete with sand filters.

In case the hardly oxidized substances that retard biochemical processes or cause frothing are present in liquid the floatation may be one of the main methods of decontaminating these substances.

The characteristic feature of floatation. The method is the possibility of using the latter for treatment of large as well as small amounts of waste liquid. Floatation plants are distinguished by compactness which makes it possible to locate them right at places of waste water generation. The operation of floatation plants can be automatized in a simple way which in turn ensures secure operation of these plants and affords to gain for high efficiency of treatment.

The following kinds of floatation are being used at present for treatment of natural and waste water as well as for treatment of sediments and activated sludges:

compression (pressure), impeller, vacuum, biological chemical, electric and ionic floatation, froth separation.

In all these cases the removal of contaminants from waste water as well as consolidation of sediments takes place owing to availability of gas bubbles on the surface which is the area where the substances to be removed are concentrated. At the same time various kinds of floatation differ by a number of features: method of gas bubble generation, kinds of components to be removed (dissolved, colloidal substances, ions, molecules) design of frother cells etc.

Structural peculiarities of installations depend on the field of their use. Combination of processes in one installation is widely used at present for waste water treatment, for instance, floatation with settling, floatation with filtration, etc. It should be noted that perspectiveness of floatation increases with the development of reagent production, creation of combined schemes for physicochemical as well as biochemical treatment, necessity of surface-active agent removal, etc.

The efficiency of floatation for waste water and sediment treatment has been proved by considerable experience of using these installations in industry and municipal services. Such floatation methods as compression and impeller one are used in practice for a long time. This made it possible to design serial (standard) installations ensuring high efficiency of contaminant removal.

Compression floatation method is widely used for industrial and municipal waste water treatment. This method is used to treat oil-containing waste water generated at enterprises or oil-producing, oil-processing and petrochemical industries, at storage terminals, ports, automobile plants as well as for treatment of effluents of cellulose-paper, chemical, power engineering, machine building and food industries, in treatment plants of municipal services.

Sufficient experience has been gained in these branches of national economy on maintenance of treatment plants, new frother cells have been designed with up to 80-98% efficiency of water cleaning from suspended matter and oil products. Considerable reduction of COD (chemical oxygen demand) and BOD (biological oxygen demand) values of liquid has been achieved.

Several modifications of floatation plant systems are used for waste water treatment. These plants include:

liquid supply pump, ejector or compressor for air delivery into system, saturator (capacity for air dissolving under pressure of 3-5 atm), frother cell. The plants can have special inlet devices for reagents and as a rule are provided with automatic control and regulation system.

Schematic diagrams of some of these systems are shown in fig. 1.

Depending on the amount of liquid supplied to saturator these diagrams can be classified as follows:

- straight-flow, when the total amount of treated liquid is supplied to saturator (diagram a);

- recirculation, when 20% of clarified liquid and more than that is supplied to saturator (diagram δ);

- partially-straight flow, when about 30-70% of non-treated liquid is supplied to saturator and the rest of it is sent directly to frother cell.

These diagrams can be completed by a number of facilities, such as mixing and flocculation chamber in case of reagentizing, devices for air and water-air mix dispersion etc.

The field of using these systems is determined by physicochemical properties of treated liquid and its components, by requirements to quality of treatment and by local conditions.

Straight-flow system is used in industry to remove the major part of contaminants from waste water when it is necessary to inject considerable amount of air and gain high efficiency of treatment.

Straight-flow system ensures sticking of generated micro-bubbles of air right to contaminant particles in waste water and thus provides for a high efficiency of treatment.

Floatation with recirculation is used to treat waste water containing contaminants that can be easily dispersed for instance, in the process of water pumping, during air dissolving or in case of liquid treatment in saturator.

These are flocculant suspended matter, activated sludge and some metal hydroxides that can be easily subjected to such changes. In this case treated waste water is used as working fluid to involve air in floatation process. Such water is also used in floatation plant.

Mixing of contaminated liquid with air-water mixture takes place in a piping located in front of frother cell or right in the installation.

The process of generating and fixing microbubbles on contaminant particles in this system will have some pecularities as compared with straight-flow floatation. In case of recirculation the microbubbles are formed, as a rule, in a clarified liquid layer up to the point where it is mixed with waste water as it is subjected to a lesser pressure. That is why the possible contact between generated bubbles and contaminant particles depends on mixing conditions and affects floatation efficiency. This system is used in case of activated sludge treatment, final purification of biologically treated waste water, when making use of reagents and also when it is necessary to reduce power consumption, etc.

Partially straight-flow floatation system is used when it is necessary to remove the bulk quantity of contaminants from waste water in case of local treatment of industrial waste water and gaining valuable components before biological treatment plants and final treatment. Plant operation according to this scheme provides high efficiency of treatment when using reagents. As compared to the previous schemes this one provides considerable reduction of power consumption.

To maintain the process of water saturation with air or gas, provision is made in pressure floatation plants for saturators working at a pressure of 3-5 atm. The period of liquid staying in saturators is from 0.5 to 2 minutes.

Depending on the quality of treated water use is made of saturators (absorbers) of bubbling, dispersion and cap type. Schematic diagrams showing some of these saturators are given in fig. 2.

The required period of liquid staying in the saturators is determined by calculation and depends on phase contact surface, mass transfer coefficient and impellent force of the process.

Bubbling type saturators (a) are used to treat liquid containing considerable amount of suspended matter, part of it having adhesive properties. Phase contact surface is formed by gas or air bubbles which bubble the liquid.

Dispersion type saturators can be successfully employed when using well dissolved gases for waste water saturation.

Various spraying devices are used in these installations.

Combined type saturators (B, ) provide better saturation of water with air especially in case of using capping. Bubbling type saturators are most frequently used for waste water treatment and sediment processing.

Such apparata are also used for the majority of floatation plants designed for oil products removal.

More efficient are saturators equipped with capping. Plates of different shape, grates, rings, nets etc. can be used as capping. Arrangement of these elements in the saturator affords to increase greatly phase contact surface.

Investigations carried out by VODGEO in industrial conditions have shown that the use of saturator with a capping for treatment of oil-containing waste water allows to reduce the period of liquid staying in the apparata and to increase the amount of dissolved air as compared with conventional installations having bubbling layer of liquid.

Some researchers have suggested at present the schemes of presure floatation provided with saturators have centrifugal nozzles, Venturi tubes and other devices which makes it possible to reduce the period of liquid staying in the apparata up to 30-60 sec.

Pressure floatation plants are available in our domestic industry which do not contain saturators, and the process of air solution takes place in pressure piping which supplies waste water to frother cell.

Separation of contaminants from waste water by means of floating up gas and air bubbles is performed in a frother cell. Horizontal, radial and vertical type cells provided with devices for froth skimming and bottom sediment removal are used for waste water treatment by pressure floatation method. Considering that waste water includes hydrophilic particles and other admixtures which cannot be separated with the help of floating up bubbles. Cells are also designed for liquid settling (flotators-settlers) or include filtering bed (filter-flotator).

Key diagram of some frother cells of more than 300 $m^3$/hr capacity are shown in fig. 3.

Frother cells (fig. 3a) are used to treat waste water containing substances with hydrophobic properties as well as oils, oil products, fats and surface-active matter. These installations are provided with a device for continuous froth removal. Bottom deposit formed in a small quantity is periodically removed. The operating capacity of the plant reaches $m^3$/hr. The efficiency of treatment, for instance, oil-containing waste water (straight-flow system) is 50-60% and in case of reagent use up to 70-85%.

These installations were employed to treat industrial waste water before biological installations or for additional water cleaning from mechanical impurities.

Flotators-settlers (fig. 3b) are more widely used for treatment of industrial waste water and in some cases for final treatment of biologically cleaned waste water.

These installations up to 1200 $m^3$/hr capacity and over are equipped with froth skimming device.

The sediment formed in the installation is periodically removed thus confining the field of using these installations for treatment of waste water as the latter mainly contains easily flotable matter.

These installations operate with a higher treatment efficiency as compared to above mentioned frother cells. They are used in some systems for treatment oil-containing waste water as well as in chemical industry.

More efficient are flotators-settlers provided with scraper device for continuous sediment removal.

New installation have been designed with the capacity from 300 up to 900$m^3$/hr. Use of these installations for treatment of oil-containing waste water provides oil products removal to their residual concentration of 20-30 mg/l. Use of flocculants in these conditions makes it possible to remove oil products to residual concentration of 10-15 mg/l.

Water treatment efficiency by means of flotation depends also on hydrodynamic conditions in frother cell. Availability of stagnant zones in installations and created convective flows of liquid cause intensive movement of water in various directions and make floatation process worse.

To improve hydrodynamic conditions of the process provision is made for new designs of floatation installations containing various types of headpieces.

Frother cell with a cylindrical headpiece (fig 3, ) made of polymers or metal have been suggested for treatment and final purification of biologically treated waste water and compaction of activated sludges.

Installations of 250 m$^3$ hr capacity have been designed with scraper devices for froth skimming and sediment removal.

These installations were also used in systems of additional reagent treatment of waste water.

Horizontal frother cells with units of flat parallel plates (fig. 3 -2) and 1-1.5 m depth of liquid working layer are also used to treat industrial waste water. A proportional water distribution device is provided at installation inlet to maintain adequate water distribution. Such apparatus of up to 80 m$^3$ hr capacity makes it possible to remove oil products to residual concentration of 5-10 mg l in case of reagent usage.

Wide use is made of horizontal frother cells (fig. 3 ) to treat small quantities of industrial waste water.

Installations of 5-20 m$^3$ hr capacity comprising saturator equipped with water delivery pump and air injection device as well as rectangular frother cell are produced by our industry.

This brief list of described frother cells does not cover the variety of possible structures.

As it has been already mentioned use is made in waste water treatment systems for combined structures filters-flotators. Such apparatus devised in food industry is shown in fig. 4.

Saturated water and air mix is supplied to floatation zone located in the upper part of the apparatus. The filtration zone is formed of sand bed of about 1 m thick.

This apparatus operating on waste water of one of the mills of butter and fat industry provides for high water treatment efficiency at 3 m$^3$ m$^2$ hr load and 25-50 mg l flocculant doze, including that for fat matter from 50 mg l to residual concentration of 1 mg l. This filter-flotator is recommended to treat waste water of varnish and paint industries where it was shown by investigations the efficiency of cleaning from suspended matter reaches 96%.

Other structures of filters-flotators have been also designed which are recommended to treat various kinds of industrial waste water.

The authors consider that the apparatus shown in fig. 4 can be used to treat natural and waste water.

Floatation method of activated sludge compaction is maintained in some of presented structures, in apparatus shown in fig. 4 . This apparatus of up to 100 m$^3$ hr capacity operates according to recirculation scheme. The period of liquid staying in it is about 40-60 minutes, the height of working zone is up to 3 m, the moisture content of compacted deposit is about 95%, the content of suspended matter in treated water is 30-50 mg l.

Along with compression floatation it is recommended to use frother separation for final treatment of biologically purified waste water. The scheme of apparatus designed to clean waste water of textile and tannery plants from synthetic surface active matter is shown in fig. 5. Air of about 12 m$^3$ m$^2$ hr intensity is delivered into this apparatus through porous material.

With aeration period of about one hour the efficiency of surface-active matter removal is up to 60%, the reduction of COD and BOD of waste water is up to 25-40%. Some other designs of apparata for surface-active matter removal by bubbling method have been also suggested (fig. 5b).

One of the floatation methods that special attention is being paid to is electrofloatation. Electrofloatation gives the possibility of getting microbubbles of gas which are uniformly distributed in the treated liquid.

Use of electrofloatation for treatment of oil-containing waste water makes it possible to reduce the content of oil products up to 1-10 mg l with original concentration being 200 mg l. Power consumption in this case is 0.28-0.55 Kw per m$^3$ of treated water.

Electrofloatation is also efficient for final treatment of biochemically purified waste water of oil refineries.

With current density of 17 ma cm$^2$ and treatment period of 4 minutes the content of suspended matter in waste water is reduced from 15 mg l to 2 mg l, the COD value is reduced from 175 mg l to 14 mg l and the content of ester matter from 11 mg l to 4 mg l.

Electrofloatation plants of up to 10-15 m$^3$ hr capacity are usually provided with one cell and for greater efficiency – with two cells. The apparata is usually comprised of electrode compartment and settling part. Waste liquid enters the calming basin separated from electrode compartment with a grate. Floating up of particles take place in the settling zone. The floated sludge is removed by scraper devices.

Use is made of either insoluble electrodes (in case of small content of contaminants) or of soluble electrodes (in case of aggregate-resistant contaminants with high concentration). The gap between the electrodes is usually 15-30 mm.

As it has been already mentioned it is not possible to present here the whole variety of designed flotator structures with their schemes, but it should be pointed out that this method of treatment will be widely used for waste water treatment.

For the sake of further development of methods and structures of flotation plants for waste water purification and sediment treatment attention should be paid to the following aspects:

- increasing operating efficiency of devices for dissolving air and gas in liquid;
- providing optimum conditions of flotation separation of gas and liquid medium;
- studying hydrodynamic conditions of frother cells (velocity of flow and bubble movement as well as generation and movement conditions of aeration floccules;

- studying physical and chemical properties of water-air medium;
- creating reagents for flotation treatment of waste water and compaction of sediments and activated sludges;
- studying flotation process accompanied by sorption, adsorption, oxidation, etc;
- designing combined installations (coagulator-flotator, filter-flotator, flotator-degasator, flotator-settler);
- studying the peculiarities of flotation treatment of waste water and final treatment of biologically purified water with activated sludge compaction;
- designing devices for froth removal, its processing and gaining valuable components;
- designing automatized flotation plants;
- generalizing the operational results of flotation plants and their technical and economic evaluation.

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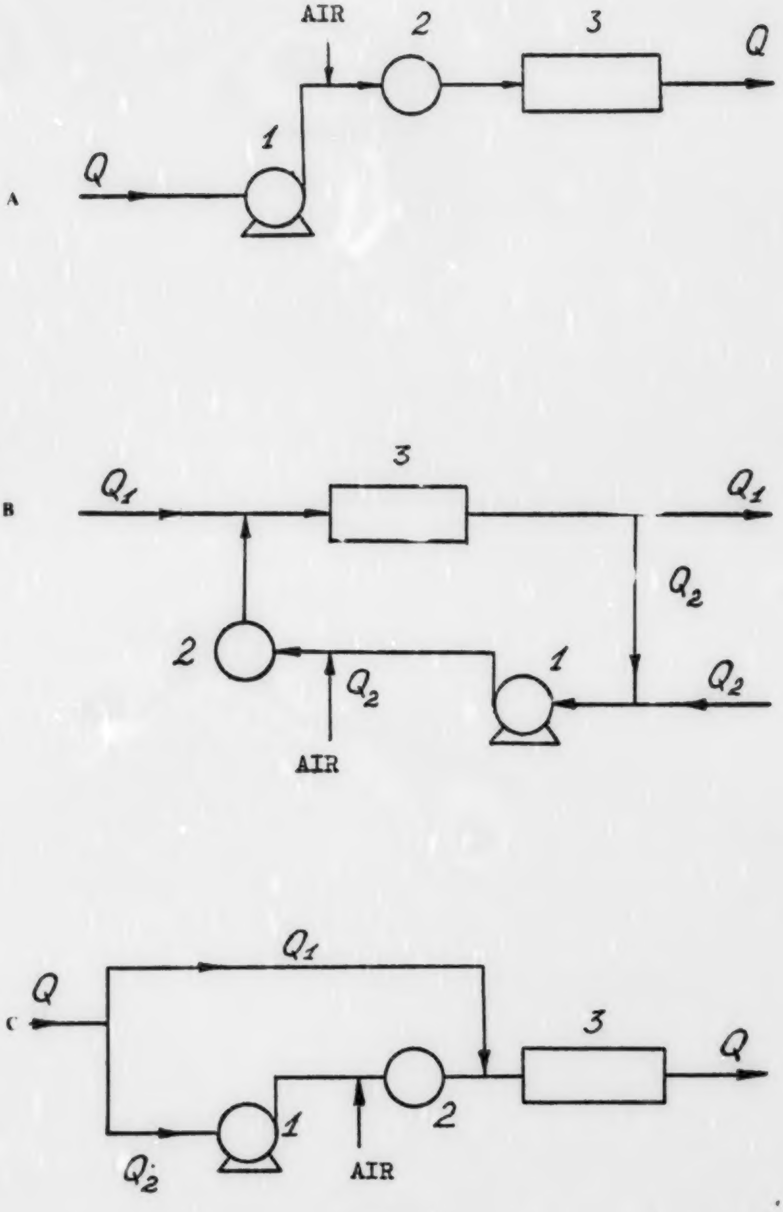

**Figure 1.**

**Principal Scheme of Flotation Unit**

A. Concurrent type
B. Recycle type
C. Partly concurrent type
1. Pump for influent
2. Saturator
3. Flotation cell

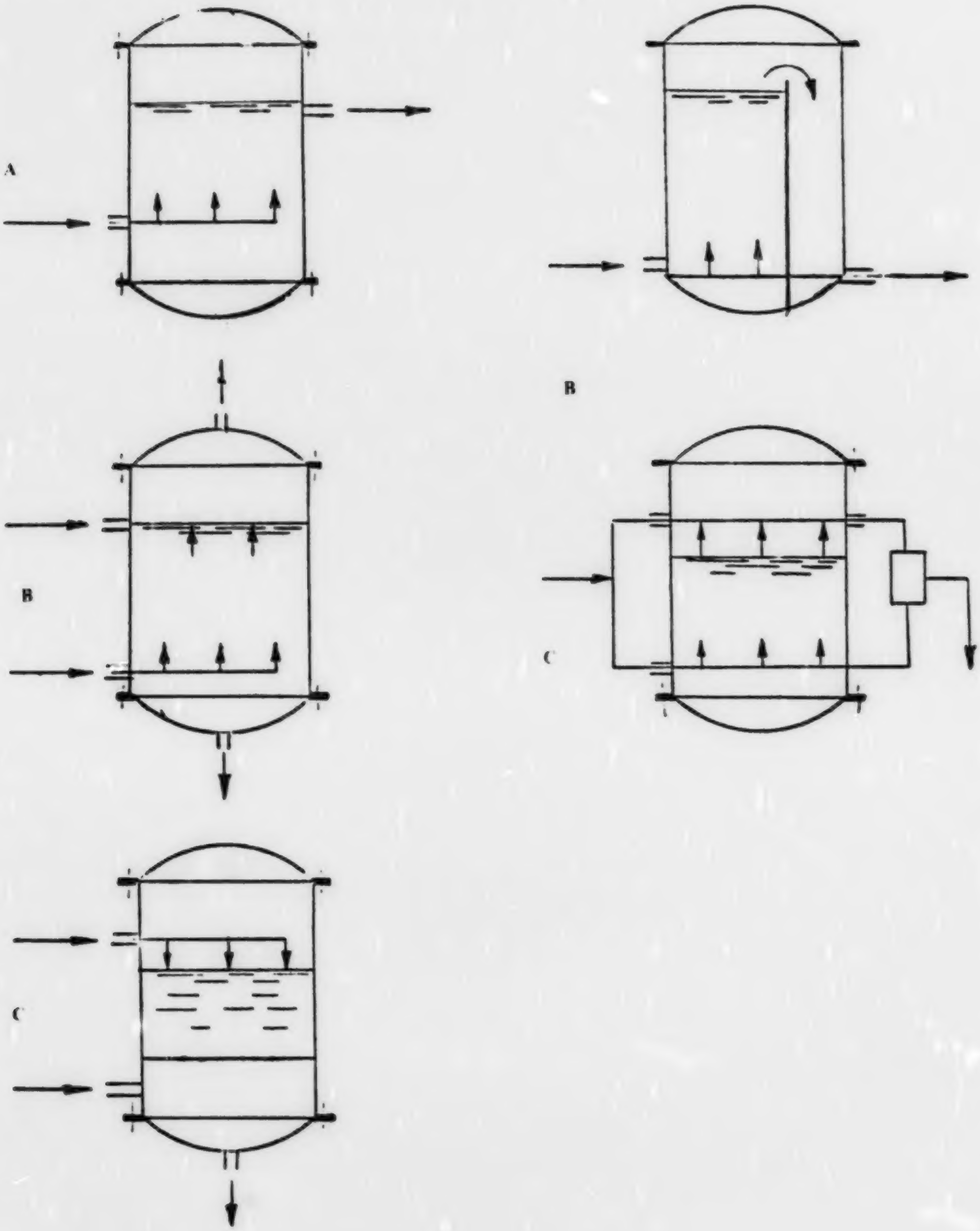

Figure 2.

**Principal Scheme of Saturators**

A. Barbotage type
B. Hollow spray apparatus
C. Combined type
D. Nozzle type

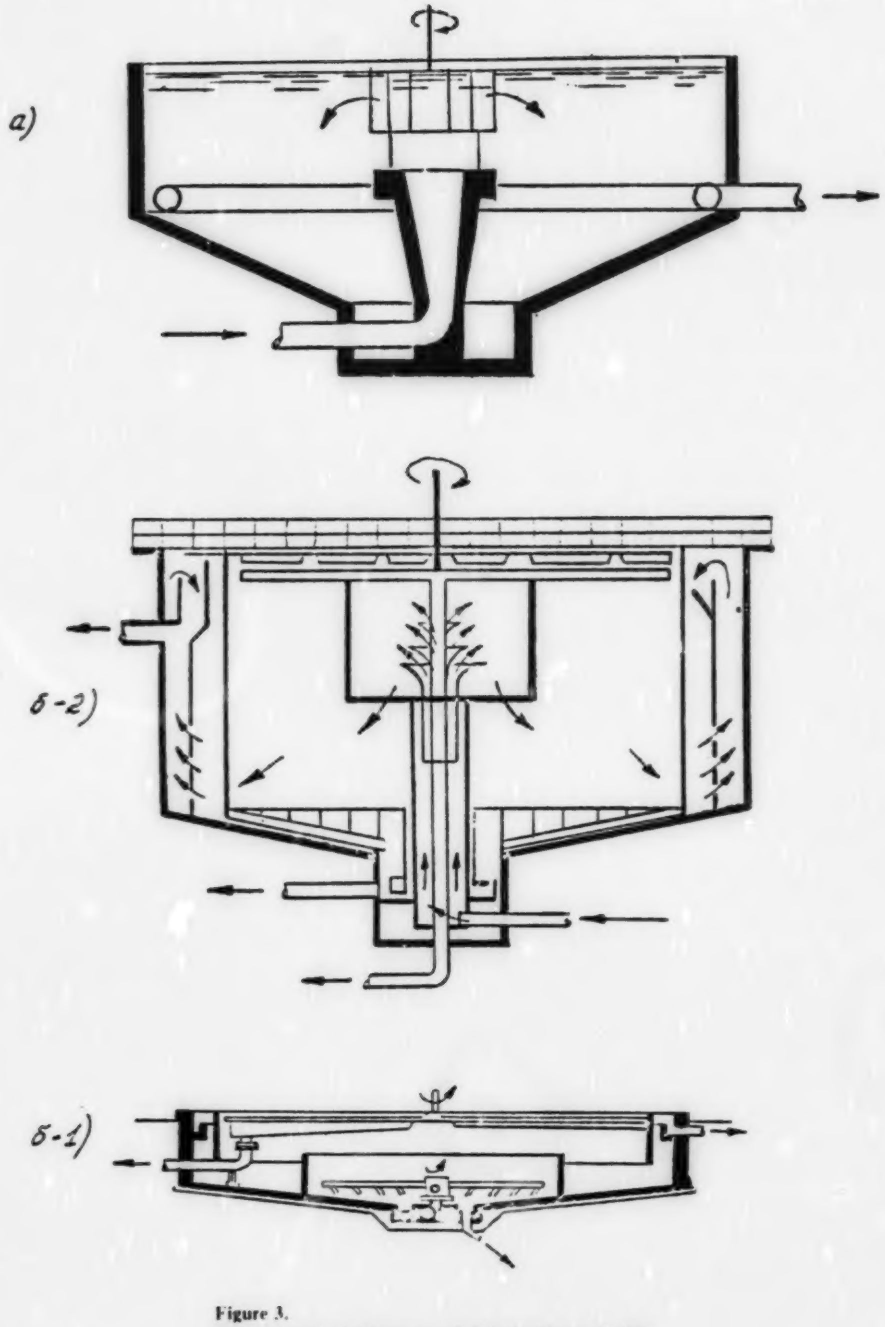

**Figure 3.**

**Principal Scheme of Flotation Cells**

A. Flotation unit
B. Combined flotation-sedimentation tank
1. Flotation-sedimentation tank with mechanisms for foam and sludge disposal

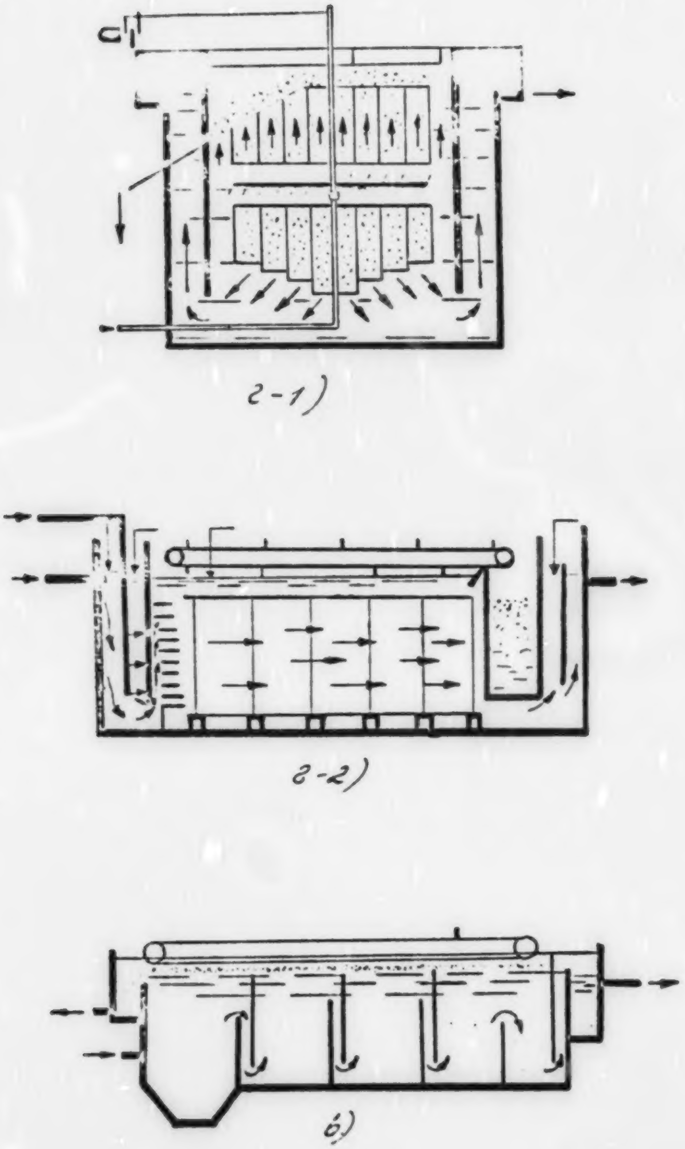

**Figure 3.1.**
**Principal Scheme of Flotation Cells**
1. Sectioned flotation cell
2. Flotation cell with nozzle of 1) annular type and 2) rectangular type

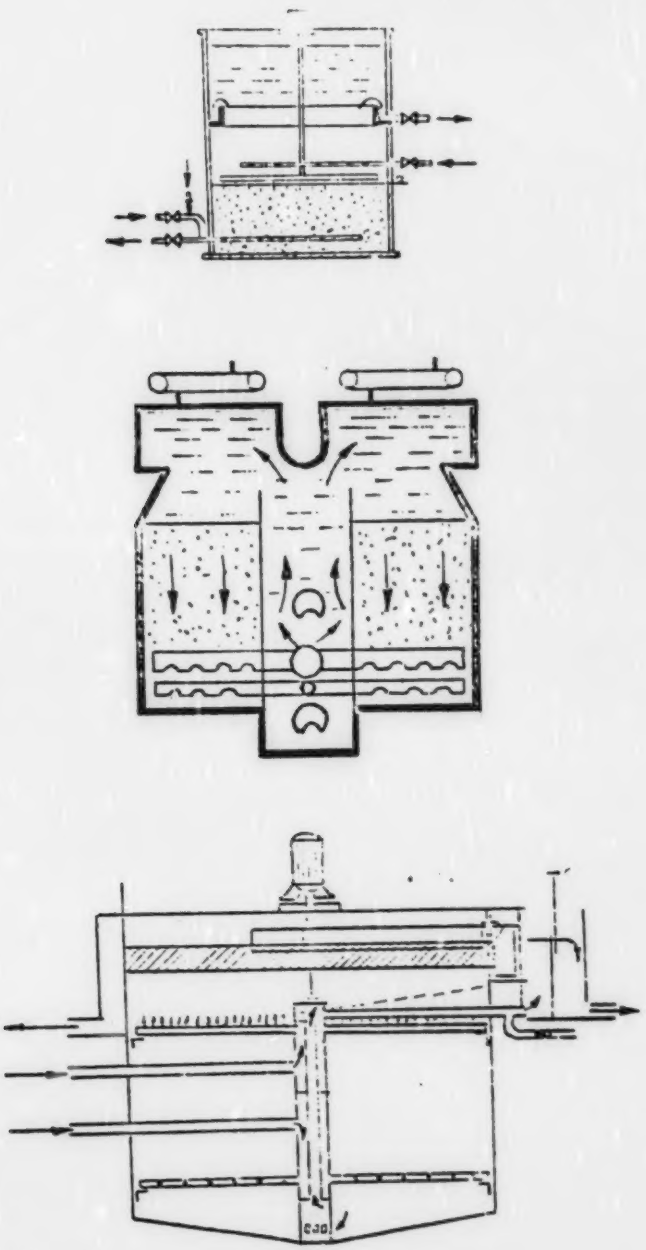

Figure 4.
**Principle Scheme of Flotation-filtration Unit (a) and Sludge Thickener (b)**

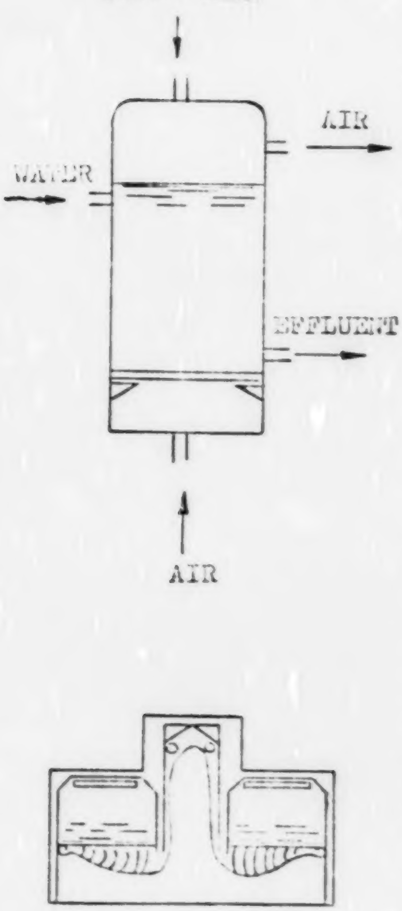

Figure 5.
**Scheme of Foam Separating Cells**
1. Barbotage one-sectioned cell
2. Barbotage two-sectioned cell

# Performance Tests on Full-Scale Tertiary Granular Media Filters

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## Introduction

Filtration is considered to be the most important tertiary process in the implementation of the Federal Water Pollution Control Act Amendments of 1972. Based on tertiary filtration needs reported by Lykins and Smith(1), over 1500 plants will be required to achieve current water quality standards. Approximately 94 percent of plants will be smaller than 5 mgd and 80 percent will be smaller than 1 mgd. An equivalent number of plants will be required to meet anticipated future standards by 1985.

This paper summarizes the results of a full-scale evaluation of 8 small-scale (0.8-2.5 mgd) tertiary granular media filtration plants in the Chicago metropolitan area. The objective of this portion of the study was to characterize filtration plant performance as a function of design and operational variables.

## Data Collection

All analyses were made on flow-proportioned composite samples of secondary effluent (filter influent) and filter effluent. Most sampling periods were 24 hours, with occasional periods of 4, 8, and 16 hours. Samples were analyzed for turbidity, suspended solids, and 5-day BOD on a routine basis. Flow rate was obtained from plant meters and run lengths were determined from backwash frequency counters. Headloss at the end of runs was determined if filters were equipped with altitude gauges.

## Filtration Plant Design

A summary of filtration plant design data is shown in Table 1. Chemical treatment of secondary effluent prior to filtration, except for chlorination, was not practiced at any of the plants. Five plants have filter configurations shown in Figure 1 with a backwash storage tank located above the sand and anthracite filter media, and flow-splitter box for proportioning flow to individual filters (Smith & Loveless, General Filter, and Eimco designs). Adjustments were made to weir lengths in the splitter boxes for the Addison South, Lake Zurich, Lisle, and Marionbrook Plants to vary the flow from approximately 0.5 to 2 times average for 3 filters. The Environmental Elements (Hardinge) and Hydro-Clear designs utilize single medium sand filters, and the Neptune Microfloc design utilizes tri-media of anthracite, garnet, and silica sand.

Geometric mean media sizes ($d_{50}$) varied from 1.4 to 2.7 mm for anthracite and 0.6 to 1.4 mm for sand. Design depths ranged from 12 to 24 in. for anthracite and 10 to 24 in. for sand. Actual depths when sampling was conducted were considerably less for many plants because of media loss during backwashing since the plant was constructed or the media last replaced.

## Average Performance Data

A summary of average flow and suspended solids data is shown in Table 2. Coefficients of variation for influent suspended solids ranged from .33 to .60 while for effluent suspended solids the range was .25 to .80, indicating a wider range in effluent than influent characteristics during the sampling periods. The average ratio effluent to influent suspended solids ($\overline{C/C_0}$) varied from 0.17 to 0.53 for the 8 plants.

Plots of $\overline{C/C_0}$ vs. average flow rate ($\overline{Q}$) and average influent solids loading ($\overline{C_0Q}$) are shown in Figures 2A and 2B, respectively, for plants where flow was varied to individual filters. Although the independent variables $C_o$ and Q varied widely as did $C/C_o$, the average performance ($\overline{C/C_o}$) and effluent suspended solids ($\overline{C}$) appear linear with flow rate. For individual data it is not possible for both relationships to be linear unless $C_o$ is constant and $\overline{C}_o$ is constant for each data point for Lisle and Addison South plants. For those plants data was obtained for low, medium and high filtration rate simultaneously. The more nonlinear dependence apparent for the Lake Zurich (LZ) and Marionbrook (MB) plants may result from the fact that the three filters (low, medium and high rate) were not always in operation at parallel times and thus $\overline{C}_o$ is not constant for each.

Figures 3A and 3B show average effluent suspended solids (C) as a function of flow and solids loading for the Addison South and Lisle plants. Data for the Lake Zurich and Marionbrook Plants are excluded from this plot because $C_o$ was not constant as already mentioned. As with average data for $C/C_o$, a linear dependence of C with Q and C with $C_oQ$ is apparent. Linear correlation coefficients for all pairs of data in each of the data sets is shown on Figures 2 and 3. The Addison plant (AV) shows highest ($r=0.70$) correlation of C with $C_oQ$. Remaining data sets on Figure 3 shown marginal correlation ($r < 0.5$) and some data sets in Figure 2 shown no correlation individually, e.g., Lake Zurich and Lisle on Figure 2B.

Particle properties, particularly suspended particle size and suspended particle size distribution are expected to play important roles in granular bed tertiary filtration (2, 5, 6). In this phase of the work, no routine quantitative measurements were made to determine particle size distributions. However, it was observed that the suspended solids for the Lake Zurich and Marionbrook plants secondary effluents were more finely divided compared to the other plants. This is not surprising since both plants have ponds ahead of tertiary filtration. The secondary processes for the Lake Zurich and Addison South plant consist of activated sludge and trickling filters in parallel. It would be expected that suspended solids in trickling filter plants effluents would be less flocculent compared to activated sludge plant effluents. The role of suspension characteristics are currently under investigation in this study on filtration plant performance.

Although interpretation is not possible on theoretical grounds one can linearly extrapolate the lines of best fit in Figures 2 and 3 back to very small flow rates or solids loadings. Residual values of $\overline{C/C_o}$ and $\overline{C}$ at zero flow rates or solids loadings suggests that a portion of the secondary effluent suspended solids cannot be removed by granular media filtration even at very low flow rates without alteration of suspension characteristics, e.g. particle size and charge by chemical addition.

Graphs of average $C/C_o$ as functions of average tdmperature, total media depth, and equivalent media diameter ($d_e$) are shown in Figure 4, 5A and 5B respectively, where $d_e$ is the equivalent media diameter ($d_{50}$) that would give the same clean bed headloss as the sand and anthracite media sizes at the same total depth. Values of $d_e$ were calculated form Kozeny's equation for flow through porous media. For plants where flow was varied, only data for the medium flow rates are shown.

If one excludes the single medium sand filters at the DesPlaines River (DP) and Romeoville (RO) plants, Figure 4 shows a strong dependence of filter performance on temperature (broken line) over the relatively narrow temperature range of 55 to 67° F. It is believed that this is an artifact resulting from "chance" in the selection of plants and times of the year for sampling. Alternatively, if one realizes that the Lake Zurich and Addison North plwnts had the finest and coarsest particle size respectively in the filter influent, then their average $C/C_o$ ordinate is fixed basically by this factor. Eliminating those plants and realizing that other plants had comparable filter influent particle size, $\overline{C/C_o}$ is independent of water temperature.

If suspension properties are constant, an inverse dependence of performance on media depth would be expected if in depth, rather than surface filtration, is the dominant particle collection mode. Surface cake and/or sieving filtration are believed to be the dominant modes for the sand filters at the DesPlaines River and Romeoville plants. If suspension properties are constant, higher removal efficiency should be obtained for finer media whether straining or depth filtration is operative. However, if the bulk of the removal is of coarse solids, little dependence of removal efficiency on media size or depth will be apparent, and residual suspended solids will be a relatively constant fraction of influent solids. With the information that the Lake Zurich and Addison North filter influent suspensions were coarsest and finest respectively for any plant tested then Figures 5A and 5B show that average removal of the remaining plants (with comparable influent suspensions) is independent of media depth and equivalent media diameter, the latter of which is not independent of the former. Thus, some of the filters are overdesigned with respect to media depth and size to remove the bulk of the coarse suspended solids.

## Bivariate Correlation Coefficients

Bivariate correlation coefficients for plant performance and selected operating parameters are shown in Table 3. Although performance showed a strong correlation with flow and solids loading for average data where flow to individual filters was varied, much poorer correlations were obtained for individual data.

Correlation coefficients for C to $C_o$ varied from 0.18 to 0.71. Figures 6A and 6B show C as a function of $C_o$ for the Addison South (Filter No. 2) and the Romeoville plants, respectively.

If solid breakthrough occurs before the headloss criterion is exceeded or before filters are backwashed manually or by timers, it would be expected that performance would decrease with increasing run length. Except for the Lake Zurich Plant, very poor correlations were obtained for $C$ and $C/C_0$ with run length (RL). This is partly explained by the fact that the Lake Zurich filter influent had very fine suspended solids and fully developed depth filtration took place. Thus the active deposition zone (clogging front) advances through the filter with time giving rise to a breakthrough phenomena. Furthermore, run length was varied over a wider range for this plant compared to other plants where filters were manually backwashed at the start of a run.

Except for plants where flow to individual filters was varied, correlation coefficients for $C$ and $C/C_0$ to $Q$ were less than 0.3. This suggests that, although flow is an important design parameter, day to day changes are too small compared to other variables, e.g., suspension properties, to result in measureable changes in filter performance. For plants where flow was varied to individual filters, correlations for flow increased significantly for most data sets.

## Multiple Linear Correlations

If we hypothesize that $C$ or $C/C_0$ is linearly related to variables such as solids loading ($C_0Q$), flow rate ($Q$), run length (RL) etc. this may be tested by performing multiple linear regression on the data sets. Regression coefficients for the assumed relationship were generated from a data set. Correlation coefficients for selected multiple linear regression equations are shown in Table 4. In the notation used here, the functional form of $C = f(Q, C_0Q)$ is $C = a + b\,Q + cC_0Q$, where a, b, and c are regression coefficients (constants) for data from individual plants. The highest multiple correlation coefficients obtained were 0.70 for $C$ and 0.60 for $C/C_0$).

As shown in Table 3 and Table 4, correlation coefficients for all of the Marionbrook data were less than 0.6. These data were obtained during the period from January to May, 1976, and during August, 1976. Data have been analyzed separately for both dry and wet weather periods. Prior to melting snow and heavy rains in mid-February, headloss buildup was less than 2 ft/day and in-depth filtration was believed to be the dominant removal mechanism. For this period, $C$ calculated from the multiple regression equation $C = f(C_0, C_0Q)$ is plotted versus measured $C$ in Figure 7. A greatly improved multiple correlation coefficient of 0.84 was obtained for this plot.

Data for the Lake Zurich plant have been analyzed separately excluding the data for the medium flow rate for a period when flow was not varied. The regression equation used was $C/C_0 = f\,(Q, C_0Q, QRL)$. Calculated $C$ for this equation is compared to measured $C$ in Figure 8 (multiple $r = 0.73$). Similar analyses over shorter time frames have been made for other data sets.

## Discussion

Performance of tertiary filters is the result of complex interactions between a number of variables. The relatively poor correlations between filter performance and operating parameters obtained in this study can be attributed in part to variations in the characteristics of secondary effluent suspended solids. Such changes can occur on a seasonal or daily basis, or over a shorter time frame during filter runs. Causes include changes in secondary process biota, changes in process operating modes, process upsets, and flow surges causing temporary loss of floc from secondary sedimentation tanks. Parameters of importance that were not measured routinely in this study include particle size characteristics, floc strength, and particle surface charge properties. Even so, it was found that if filtration process data are analyzed over shorter time frames where suspended solids character is more constant, improved correlations can be obtained.

Daily variations in 24-hour composite samples obtained during May to August, 1975, for influent and effluent suspended solids for the Addison South plant (Filter No. 2) are shown in Figure 9. Periods of high filter influent suspended solids for this plant are normally caused by high sludge blanket levels in activated sludge process clarifiers, resulting in part from bulking sludge and mechanical problems with return sludge pumps. Figure 9 shows that process upsets had only slight effect on filter effluent quality. Large activated sludge floc is readily removed at the surface and in the upper layers of anthracite filter media by straining mechanisms. Except for periods of secondary process upsets, filter influent and effluent suspended solids appear to vary on a random basis. The overall bivariate correlation coefficient for $C$ with $C$ is a rather low 0.38 (Figure 6A).

In pilot-scale studies on filtration of activated sludge process effluents, Tchobanoglous (2) reported that media grain size had a significant effect on removal efficiency for single medium sand and anthracite filters at depths from 18 to 30 in. Influent suspended solids levels for his studies varied from approximately 14 to 24 mg/ℓ. Small removals of suspended solids occurred below depths of 16 to 20 in. Baumann and Huang (3) reported that variations in performance over a wide range fo media sizes were not significant for dual media pilot-scale filtration of trickling filter process effluents. Trickling filter effluent suspended solids varied from 15 to 50 mg/ℓ. It was reported that no significant removal occurred below depths of 12 in. for both the sand and anthracite media. In pilot-scale studies using unstratified bed filters, Dahab and Young (4) concluded that removal efficiency is not reduced greatly by increasing the effective size ($d_{10}$) of media from 1 to 2 mm at flow rates of 2 to 4 gpm/sf. Influent suspended solids levels for their studies ranged from approximately 20 to 50 mg/ℓ.

In the studies reported by Tchobanoglous (2), influent solids levels were much lower than the averages of 28 to 62 mg/ℓ observed for the plants in this full-scale investigation. At lower solids levels, it would be expected that mean particle size would be smaller and media grain size would have a greater influence on removal efficiency than in our study.

No firm conclusions can be reached on the effect of media grain size and depth on filter performance for the full-scale plants in this study. The differences in characteristics of suspensions are most likely the major reason for the variations in performance between plants. However, based on reported pilot studies at equivalent and lower influent suspended solids levels (3, 4) it is probable that media size and depth do not have a large effect on mass removal efficiency over the ranges encountered in this study. However, media size in particular may have an effect on clogging rate.

## Conclusions

1 For plants where flow to individual filters was varied, average clarification performance decreased linearly with average flow rate.

2 Correlation coefficients between filter solids removal efficiency and operating parameters such as flow, solids loading and run length are poor for data obtained over long time frames. Improved correlations were obtained for data analyzed over shorter time periods which minimized the effect of seasonal and other variations in secondary plant effluent characteristics.

3 Run length did not have a significant effect on plant performance, except for one plant where backwash frequency was varied over a wide range.

4 Differences in characteristics of secondary effluent suspended solids rather than media grain size and depth are most likely the major reason for variations in clarification efficiency between plants.

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## Notations and Abbreviations

| | |
|---|---|
| **$C$** | Filter effluent suspended solids — mg/l |
| **$C_o$** | Filter influent (secondary effluent) suspended solids — mg/l |
| **$C/C_o$** | Rates of filter effluent to filter influent suspended solids |
| **$Q$** | Superficial filtration rate — gpm/sf |
| **$C_oQ$** | Filter solids loading — lb/sf/day |
| **RL** | Average filter run length — hrs |
| **QRL** | Flow times run length |
| **$d_{50}$** | Geometric mean media diameter — mm |
| **$d_e$** | Equivalent media diameter — mm |
| **$r$** | Bivariate or multiple correlation coefficient |

## Filtration Plant Codes

| | |
|---|---|
| **AN** | Addison North |
| **AS** | Addison South (Filter No. 2) |
| **AV** | Addison South (Filter Nos. 4, 5, 6, 7) — variable flow studies |
| **BA** | Barrington |
| **DP** | Des Plaines River |
| **LZ** | Lake Zurich |
| **LI** | Lisle |
| **MB** | Marionbrook |
| **RO** | Romeoville |

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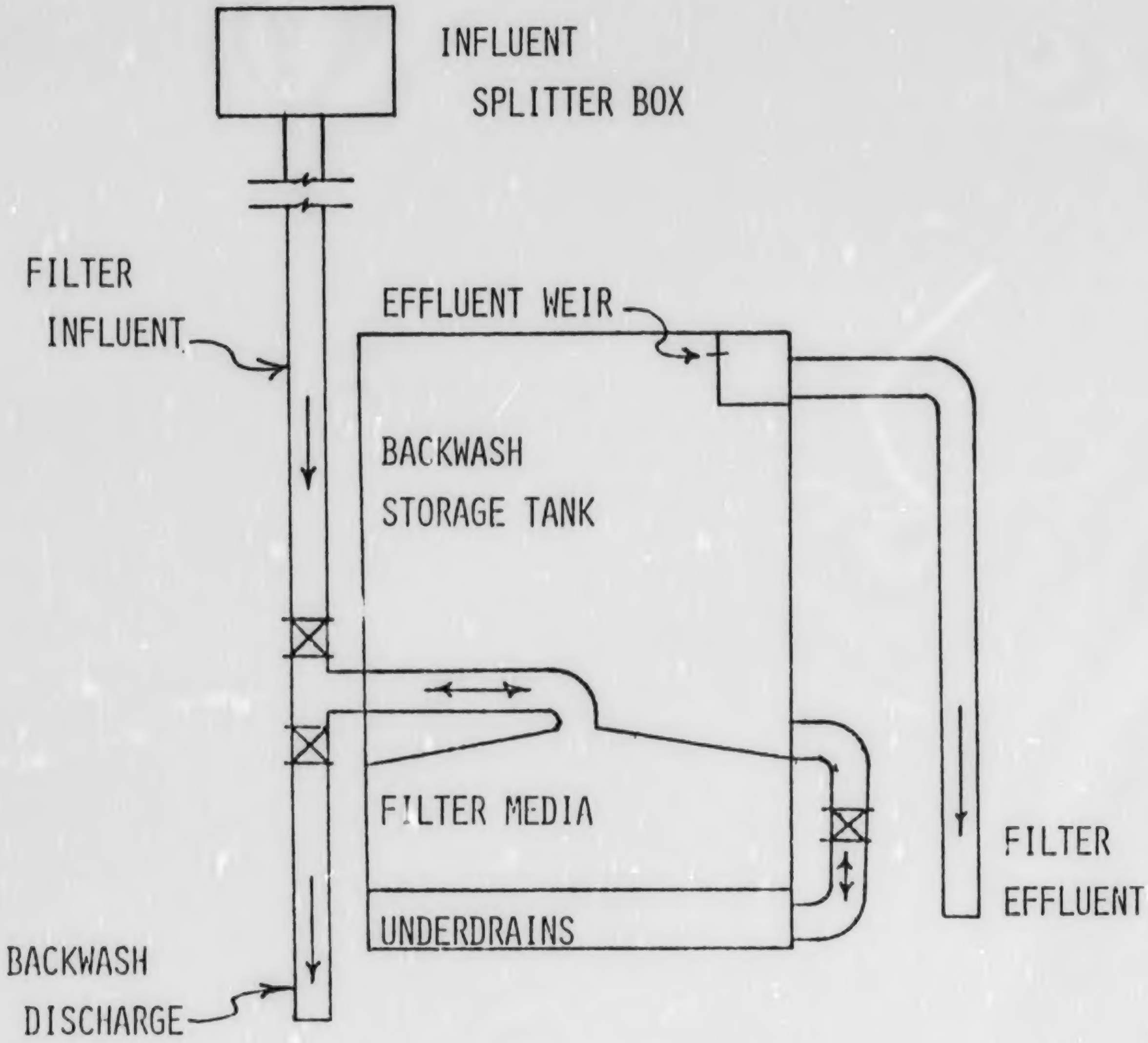

INFLUENT
SPLITTER BOX
FILTER
INFLUENT
EFFLUENT WEIR
BACKWASH
STORAGE TANK
FILTER MEDIA
UNDERDRAINS
FILTER
EFFLUENT
BACKWASH
DISCHARGE

Figure 1.
**Filter Design**

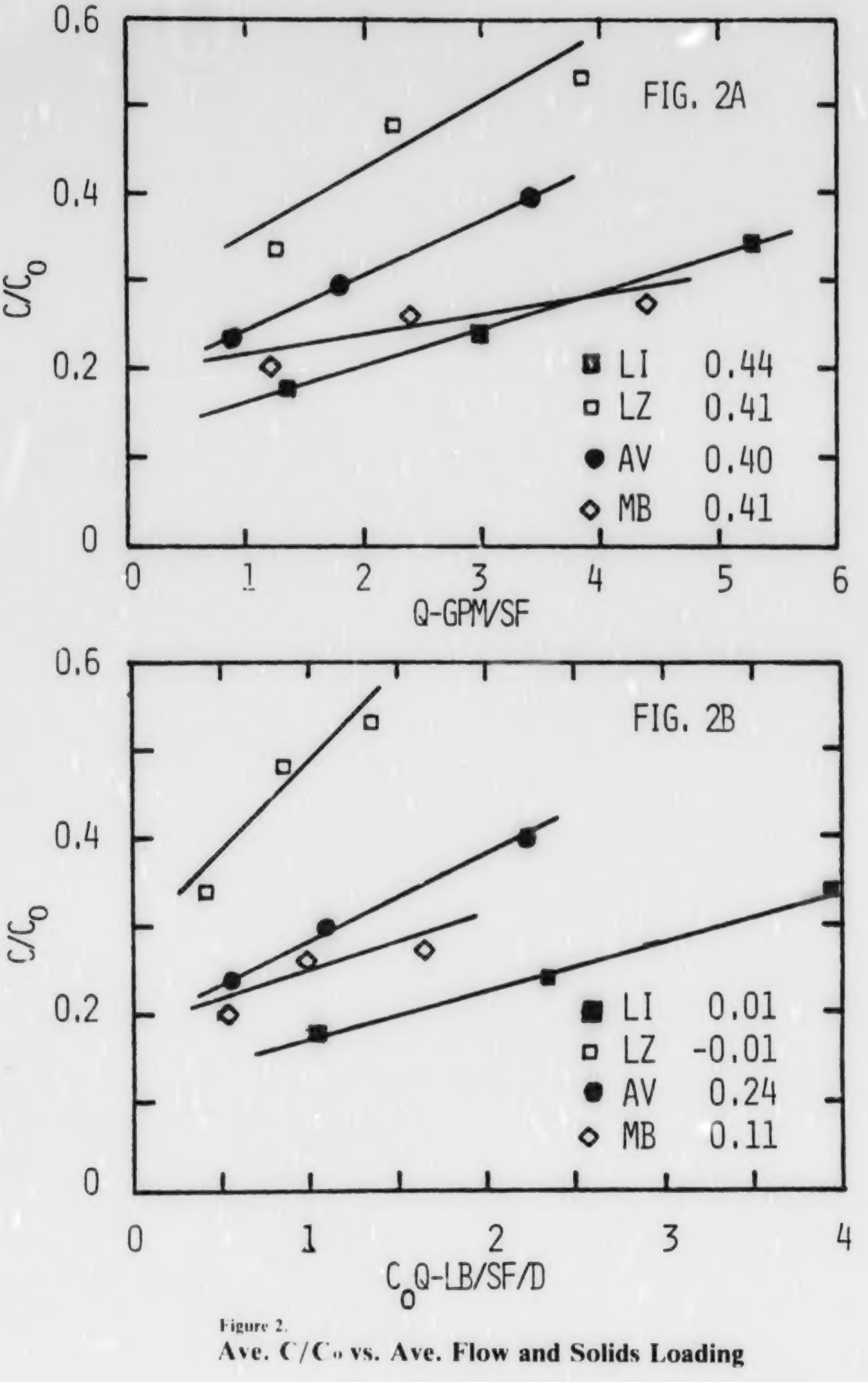


Figure 2.
**Ave. $C/C_o$ vs. Ave. Flow and Solids Loading**

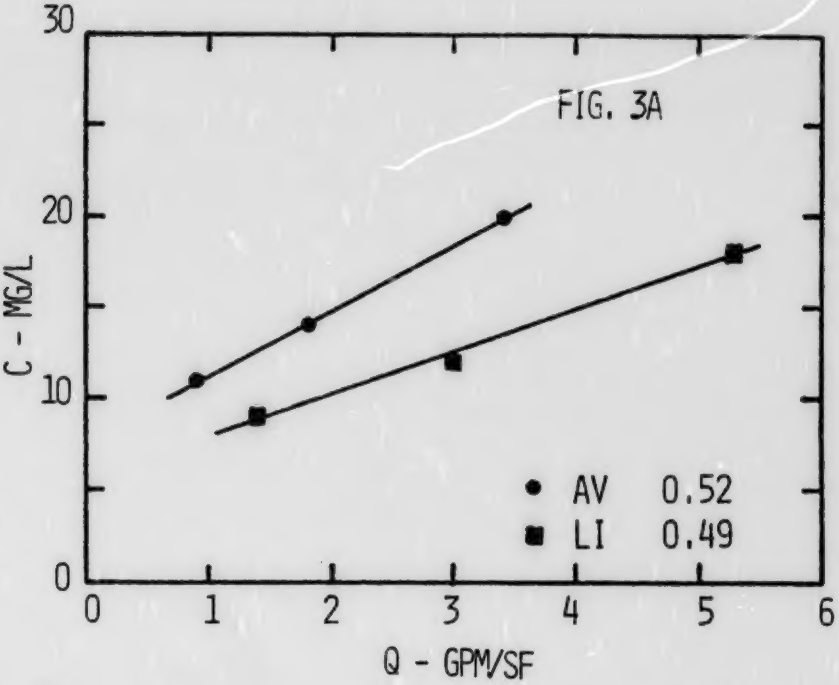


FIG. 3A

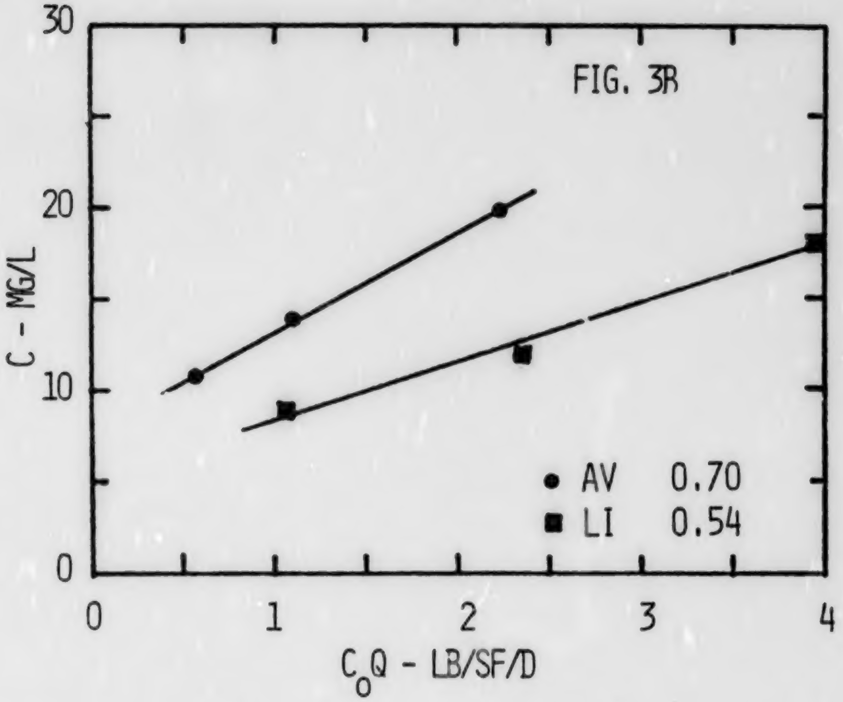


FIG. 3B

Figure 3.
**Ave. C vs. Ave. Flow and Solids Loading**

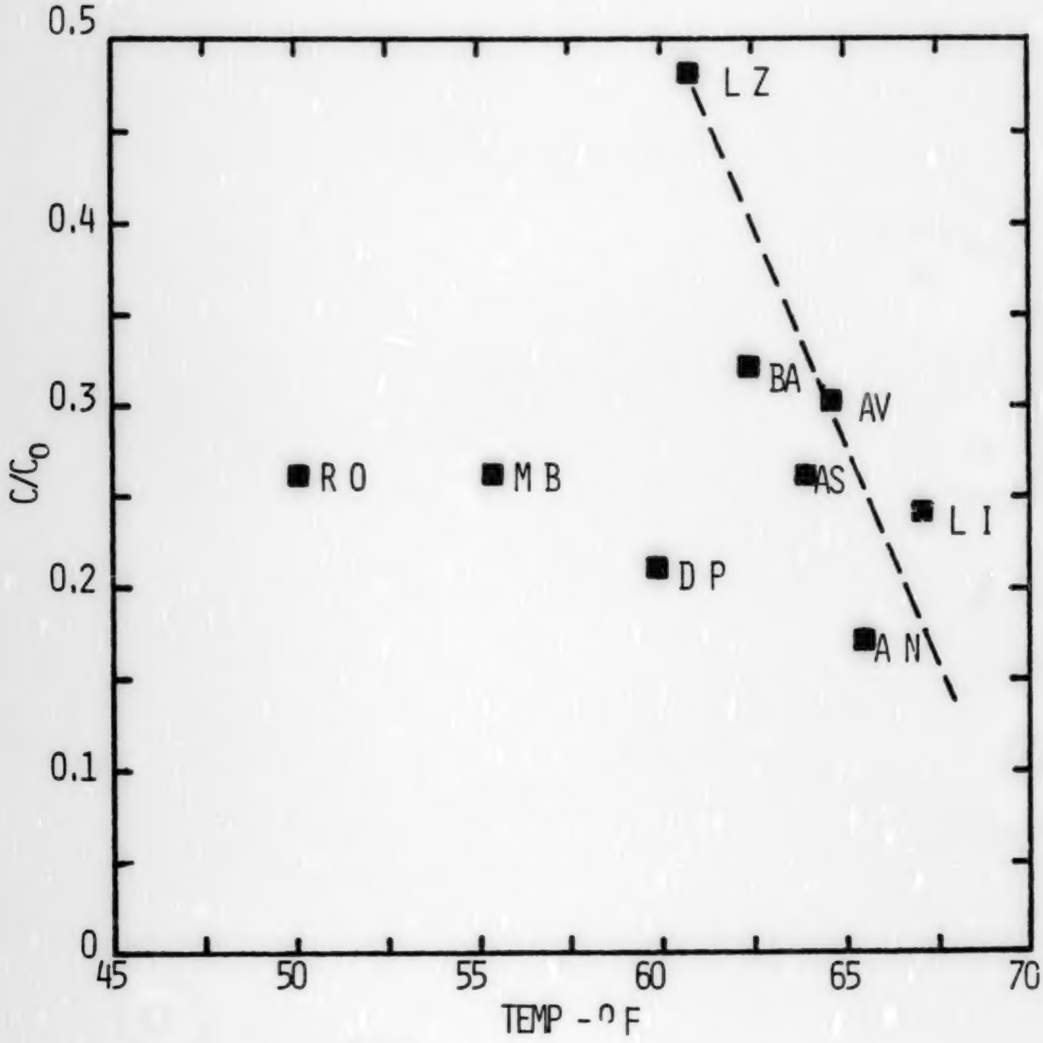


Figure 4.
**Ave. C/Co vs. Ave. Temperature**

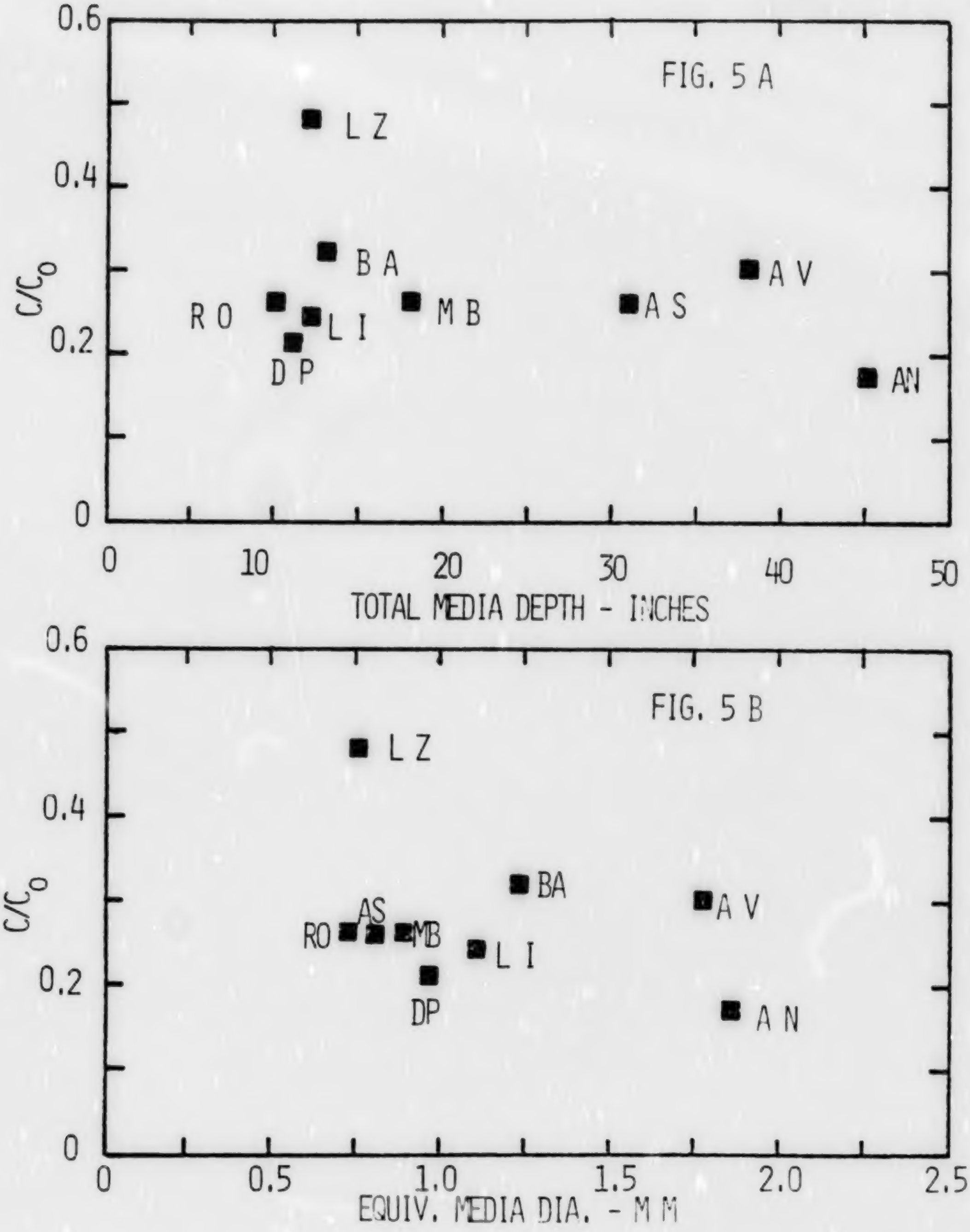


Figure 5.

**Ave. $C/C_o$ vs. Media Depth and Equivalent Media Diameter**

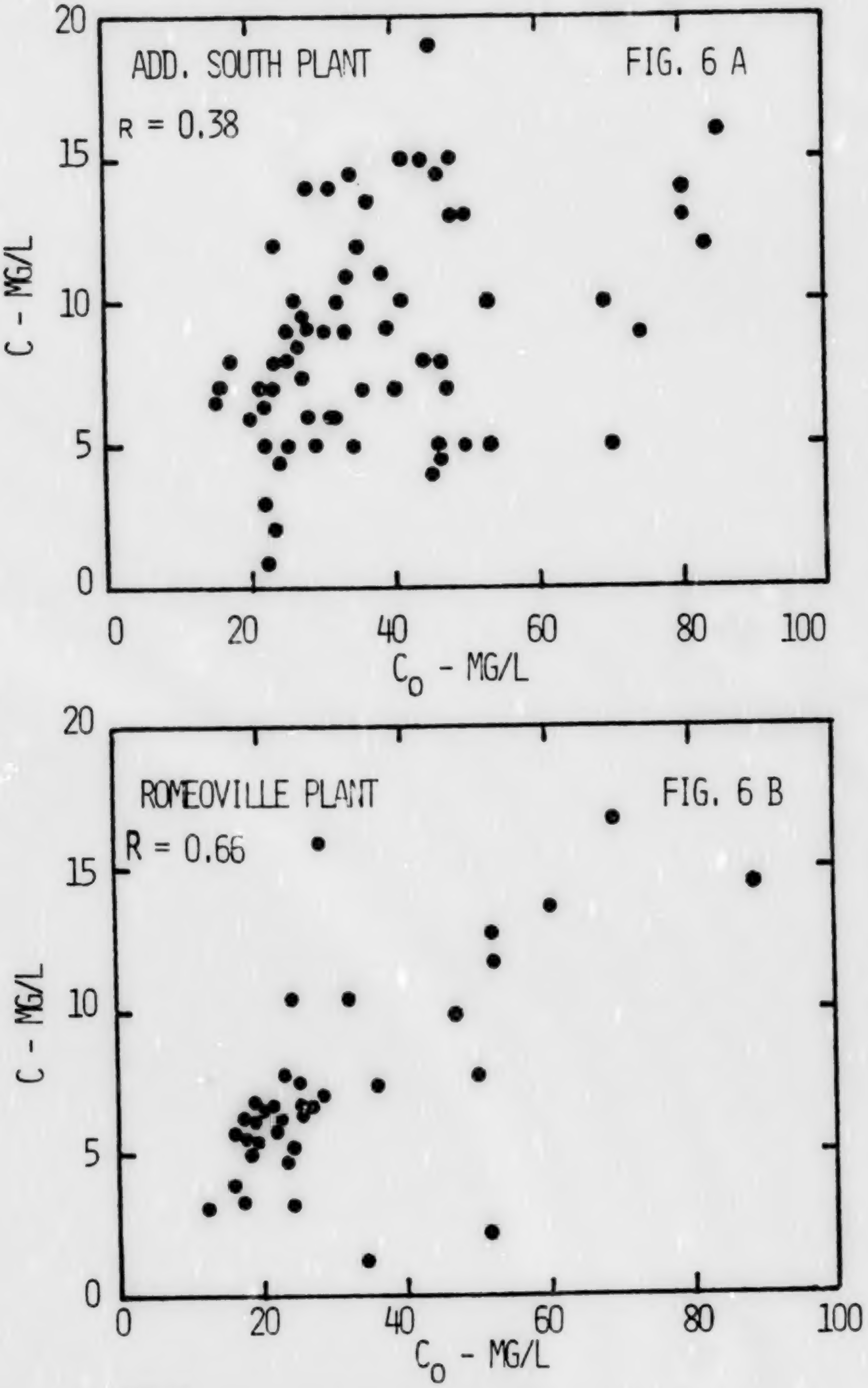


Figure 6.

**C vs. $C_o$, Addison South (#2) and Romeoville Plants**

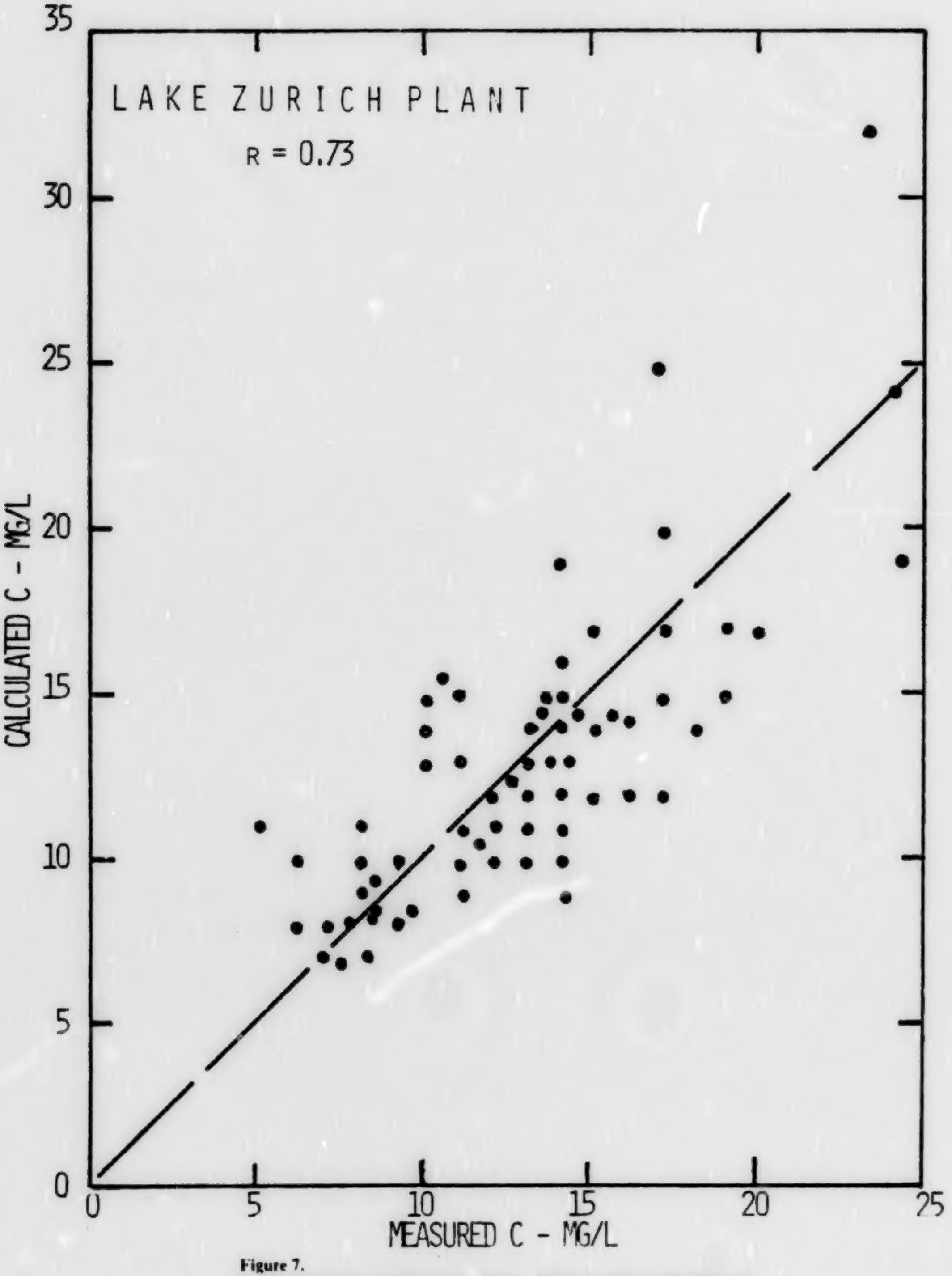


Figure 7.
**Calculated vs Measured C, Marionbrook Plant**

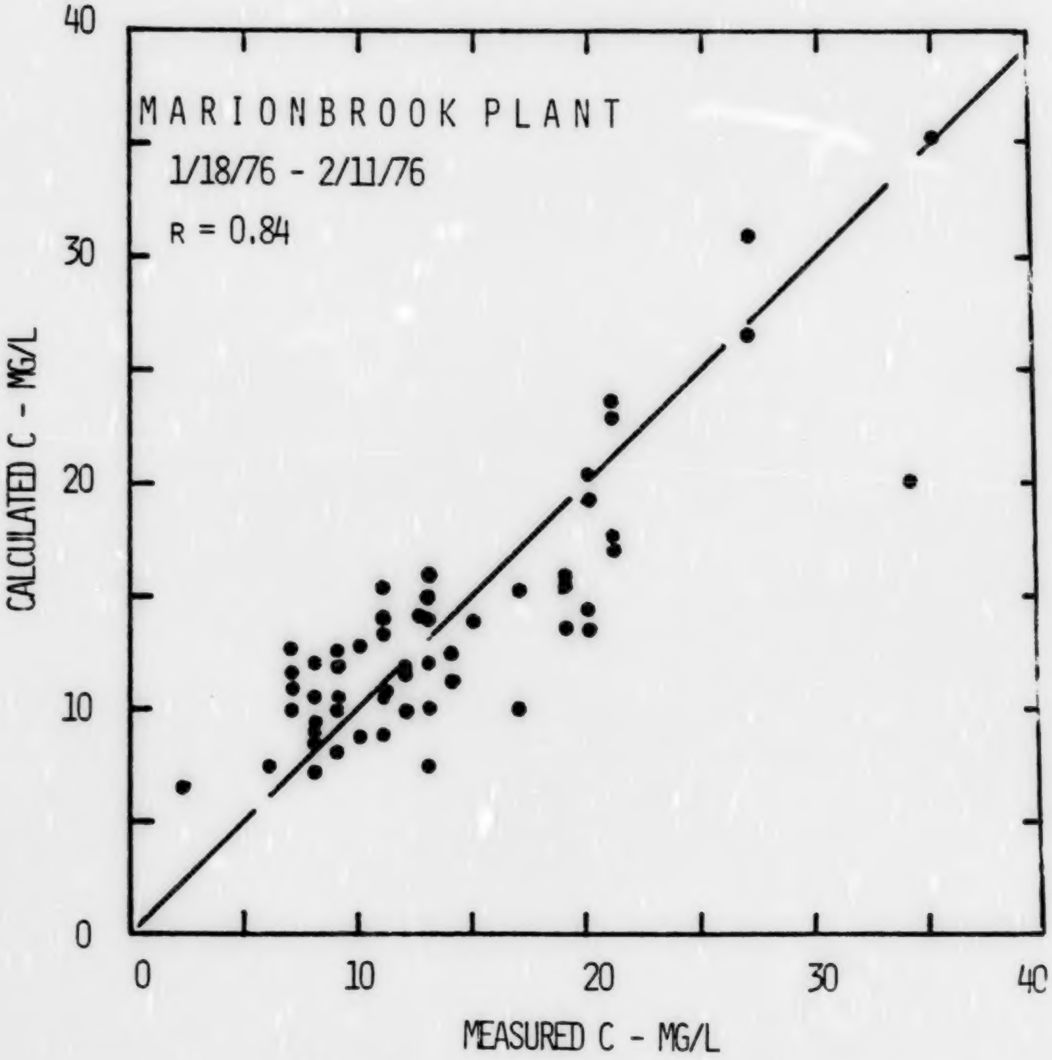


Figure 8.
**Calculated vs. Measured C, Lake Zurich Plant**

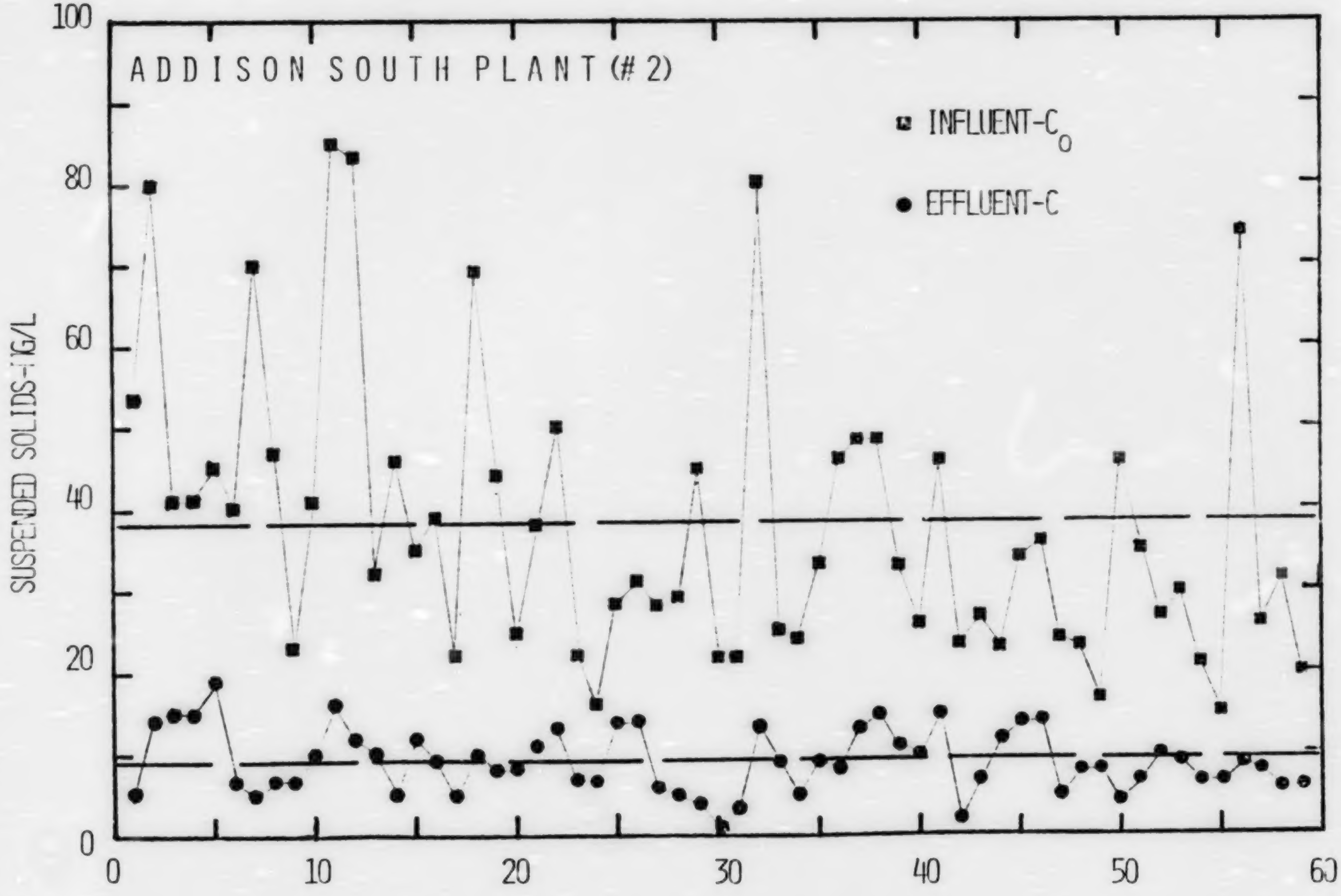


Figure 9.
Daily Changes in C and $C_0$, Addison South Plant (#)

Table 1

## Filtration Plant Design Data

| Plant | Vendor[1] | Design Flow gpm/sf | Anthracite |  |  | Sand |  |  | Sec. Plant Design Flow-MGD |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | $d_{60}$ mm | Depth Inches |  | $d_{60}$ mm | Depth Inches |  |  |
|  |  |  |  | Design | Actual[3] |  | Design | Actual[3] |  |
| Addison North | S & L | 4.3 | 2.7 | 24 | 21 | 1.4 | 24 | 24 | 2.0 |
| Addison South[5] |  |  |  |  |  |  |  |  |  |
| #1, 2, 3 | S & L | 2.2 | 1.7 | 24 | 9 | 0.67 | 24 | 22 | 2.1 |
| #4, 5, 6, 7 | S & L | 2.2 | 2.7 | 24 | 15 | 1.4 | 24 | 23 | 2.1 |
| Barrington | Nep. Micro.[2] | 3.0 | 1.76 | 16 | 10 | 0.63 | 14 | 3[2] | 2.0 |
| Des Plaines River | Envir. Elem. | 1.0 |  |  |  | 0.96 | 11 | 11 | 2.0 |
| Lake Zurich | Gen. Filt. | 2.5 | 1.4 | 12 | 1 | 0.71 | 12 | 11 | 0.8 |
| Lisle | Eimco | 2.6 | 1.7 | 24 | 9-16[4] | 0.58 | 12 | 3 | 2.5 |
| Marion Brook | Eimco | 2.5 | 1.6 | 24 | 4-13[4] | 0.66 | 12 | 10-11[4] | 2.5 |
| Romeoville | Hydro Clear | 2.5 |  |  |  | 0.72 | 10 | 10 | 2.0 |

[1] Abbrev.: S & L — Smith & Loveless, Nep. Micro. Neptune Microfloc, Envir. Elem. Environmental Elements, Gen. Filt. General Filter Co.

[2] Tri-media, 30 in. total, anthracite, garnet and silica sand

[3] Estimated depth when sampling was conducted

[4] Variation between individual filters

[5] Filters #1, 2, 3 were constructed in 1969 and #4, 5, 6, 7 in 1973

Table 2

## Summary of Plant Performance Data

| Plant | No. of Data | Flow-gmp/sf |  | Suspended Solids-mg/ℓ |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Influent (Co) |  | Effluent (C) |  | C/Co |  |
|  |  | Mean[3] | CV[4] | Mean | CV[4] | Mean | CV | Mean | CV |
| Addison North | 73 | 3.8 | 0.16 | 44 | 0.43 | 6.6 | 0.56 | 0.17 | 0.65 |
| Addison S. (#2)[1] | 70 | 2.1 | 0.22 | 38 | 0.45 | 9.0 | 0.43 | 0.26 | 0.46 |
| Addison S. (#4-#7)[1] |  |  |  |  |  |  |  |  |  |
| Low Flow | 61 | 0.87 | 0.21 | 52 | 0.42 | 11 | 0.65 | 0.24 | 0.63 |
| Medium Flow | 51 | 1.8 | 0.28 | 49 | 0.43 | 14 | 0.57 | 0.30 | 0.53 |
| High Flow | 64 | 3.4 | 0.25 | 51 | 0.43 | 20 | 0.60 | 0.40 | 0.38 |
| Barrington | 58 | 3.6 | 0.23 | 37 | 0.32 | 12 | 0.34 | 0.32 | 0.34 |
| Des Plaines River | 60 | 0.76 | 0.39 | 31 | 0.61 | 5.0 | 0.60 | 0.21 | 0.76 |
| Lake Zurich[1, 2] |  |  |  |  |  |  |  |  |  |
| Low Flow | 24 | 1.3 |  | 28 | 0.39 | 9.5 | 0.31 | 0.34 | 0.26 |
| Medium Flow | 48 | 2.3 |  | 31 | 0.35 | 14 | 0.31 | 0.48 | 0.33 |
| High Flow | 22 | 3.9 |  | 29 | 0.38 | 15 | 0.25 | 0.53 | 0.21 |
| Lisle |  |  |  |  |  |  |  |  |  |
| Low Flow | 32 | 1.4 | 0.26 | 62 | 0.61 | 9.0 | 0.51 | 0.18 | 0.50 |
| Medium Flow | 29 | 3.0 | 0.26 | 59 | 0.61 | 12 | 0.62 | 0.24 | 0.54 |
| High Flow | 35 | 5.3 | 0.17 | 61 | 0.61 | 18.0 | 0.72 | 0.34 | 0.59 |
| Marionbrook |  |  |  |  |  |  |  |  |  |
| Low Flow | 105 | 1.2 | 0.36 | 38 | 0.53 | 7.1 | 0.76 | 0.20 | 0.65 |
| Medium Flow | 100 | 2.4 | 0.31 | 34 | 0.50 | 8.4 | 0.79 | 0.26 | 0.65 |
| High Flow | 55 | 4.4 | 0.36 | 32 | 0.59 | 7.2 | 0.64 | 0.27 | 0.67 |
| Romeoville | 36 | 1.5 | 0.26 | 31 | 0.55 | 7.4 | 0.50 | 0.26 | 0.38 |

[1] Secondary process activated sludge and trickling filters in parallel. Other plants activated sludge.

[2] Filters operate at constant flow with on-off influent pump cycles.

[3] Arthimetic mean

[4] Coefficient of Variation = standard deviation arithmetic mean

### Table 3

## Bivariate Correlation Coefficients for Plant Performance Data

| Plant | C to Co | C to Q | C to CoQ | C to RL | C/Co to Q | C/Co to CoQ | C/Co to RL |
|---|---|---|---|---|---|---|---|
| Addison North | .26 | .06 | .25 | -.05 | -.07 | -.41 | -.04 |
| Addison South #2 | .38 | .02 | .31 | -.27 | .04 | -.47 | .22 |
| Addison S. (#4-7) All Data | .48 | .52 | .70 | -.10 | .40 | .24 | -.01 |
| Low Flow | .27 | .18 | .29 | -.19 | -.09 | -.25 | -.05 |
| Medium Flow | .51 | .21 | .48 | .07 | -.14 | -.21 | -.17 |
| High Flow | .71 | .53 | .74 | -.14 | .25 | .10 | -.11 |
| Barrington | .55 | .17 | .44 | .01 | -.27 | -.35 | -.15 |
| Des Plaines River | .37 | .33 | .45 | -.26 | -.10 | -.30 | -.11 |
| Lake Zurich All Data | .53 | .39 | .62 | 0 | .41 | -.01 | .18 |
| Low Flow | .47 |  | .47 | .41 |  | -.26 | .49 |
| Medium Flow | .51 |  | .51 | .12 | — | -.55 | .45 |
| High Flow | .72 |  | .72 | .09 | — | -.54 | .37 |
| Lisle All Data | .32 | .49 | .54 | .04 | .44 | .01 | .02 |
| Low Flow | .20 | .14 | .20 | .33 | -.03 | -.47 | .25 |
| Medium Flow | .41 | .55 | .44 | -.18 | .15 | -.28 | -.23 |
| High Flow | .42 | .24 | .45 | .29 | .09 | -.26 | .34 |
| Marionbrook All Data | .40 | .26 | .49 | .10 | .41 | .11 | -.04 |
| Low Flow | .43 | .47 | .72 | .05 | .53 | .11 | -.10 |
| Medium Flow | .50 | .53 | .71 | .14 | .58 | .16 | -.03 |
| High Flow | .18 | .50 | .50 | .14 | .49 | .12 | .12 |
| Romeoville | .66 | -.02 | .68 | -.12 | .25 | .26 | .15 |

### Table 4

## Multiple Linear Correlation Coefficients for Plant Performance Data

| Plant | C = f(Q, CoQ) | C = f(Q, CoQ, RL) | C/Co = f(Q, RL) | C/Co = f(Q, QRL) |
|---|---|---|---|---|
| Addison North | .26 | .26 | .06 | .04 |
| Addison South (#2) | .36 | .39 | .24 | .26 |
| Addison S. (#4-7) All Data | .70 | .70 | .41 | .40 |
| Barrington | .54 | .56 | .37 | .38 |
| Des Plaines River | .45 | .48 | .15 | .11 |
| Lake Zurich All Data | .63 | .68 | .56 | .60 |
| Lisle All Data | .57 | .60 | 46 | .46 |
| Marionbrook All Data | .50 | .52 | .42 | .44 |
| Romeoville | .70 | .70 | .36 | .40 |

# Sewage Treatment in Mining, Metallurgical and Oil-chemical Industries

**N.V. Pisanko**
("Ukrvodokanalproekt" Institute)

• The "Ukrvodokanalproekt" Institute is engaged in designing the water supply, sewer systems and hydrotechnical structures of industrial enterprises and populated points, giving great attention to the most burning problem of the present—the efficient use of water resources, protection of the nature and environment from pollution.

The largest part of the work is being carried out for enterprises of the mining, metallurgical and chemical industries.

These objects are characterized by high water flow, the use of the recycle water supply systems and treated sewage reuse.

The fundamental trends of the Institute work on the development of modern water supply systems and sewarage are the following:

- introduction of the waterless technological processes;
- decrease of the water consumption and water derivation standards;
- creation of the closed water supply cycles with the treated sewage reuse;
- introduction of the local systems of sewage treatment, with the extraction of the valuable components;
- thorough sewage treatment with application of the desalting, ozonating and sorbtioning plants;
- application of new chemicals for sewage and nature waters treatment and use of process wastes as chemicals too;
- treatment of a sewage sluge, its utilization and disposal.

A major portion of the Institute work is concerned with the experimental projection and construction of the new designs, structures and flow diagrams of water and sewage treatment.

Work is being carried out in close contact with the scientific research institutes, the plans of which for the nearest years and perspective are composed without participation.

The standard projects of sewage and water supply structures and plants for the serial use in various fields of industry are developed. Many principally new decisions of the Institute are covered by authors' certificates and have found wide use in designing and structural practice.

The peculiar attention is being focused on the development of programs and application of electronic computers, in order to choose the optimum variants in terms of techniques and economics, of the individual structures, as well as technological processes as a whole.

All the design decisions, we accept, undergo the stage of the technical and economical estimation.

The experience of operation of structures and systems, built in the latest years with new technical decisions, confirms their efficiency and economy, when compared to the traditional ones.

As examples, we may use some technical decisions, developed by our Institute and introduced into construction.

So, in mining industry, to get the ferriferous concentrate from the natural ore, the wet-separation method of its concentration is widely used, following which the large quantity of sewage in the form of a pulp-rock, strongly diluted with water, is left.

Weight ratio in the pulp of the solid phase and water T:Ж, ranges from 1:15, to 1:25.

The pulp is supplied to the tailstorage for settling, whereupon the clarified water goes back to the works.

Such a flow diagram of the pulp supply to the tailsstorage, which is located, as a rule, at a considerable distance from the oreconcentration enterprises, requires great electric energy consumption, the construction of large pulp-pumping stations with heavy equipment, as well as laying the pipelines and water mains of large length.

Our Institute developed and proposed the flow diagram of sewage clarification after oreconcentration, according to which, the pulp, before supplying to the tailstorage, is thickened up to T:Ж ratio from 1:3 to 1:1.

The clarified water goes right away to the works, and the thickened pulp is transported to the tailstorage.

In this case, along with the reduction of the energy consumption, the pipelines diameters, the number of the pumping and energetic equipment, as well as the expenses for the whole system operation, are cut down.

The flow diagram of pulp thickening is presented in Fig. 1.

From the oreconcentration plant the hydromixture by a trough is supplied to the distribution chamber 2. At the same chamber from the room of the building for chemicals 3, the flocculant solution—polyacrylamide, promoting coagulation and settling of the fine-dispersed suspension, arrives by the chemical pipeline 10.

From the distribution chamber 2 the hydromixture goes to the thickeners 4, and in case of emergency regimes, it passes by the trough 5 to the special tank.

The thickened hydromixture (sludge) enters the receiving chamber of the pulp-pumping station 7 by the pipelines 6, laid in tunnels, and then through pipelines is pumped over by the dredge pumps to the tailstorage.

The clarified water from thickeners 4 by trough 9 goes to the pond of recycle water supply 11, from where it is delivered to the oreconcentration plant. The clarified water is to be in the pond not less than 24 hours, in order to desintegrate the residual polyacrylamide.

At one of the groups of oreconcentration enterprises with the pulp consumption not more than 20 cu.m./sec., the scientific-research work was conducted, and in the industrial conditions the new type of a vertical thickener with the shelf-type medium was tested. (Fig. 2).

Compared to the radial thickener, the operation of which is based on the principle of the gravitational suspension settling over the whole depth of the settling tank, the pulp clarification in the verticle thickener with shelf-type medium takes place in a thin layer of water.

The basic design features of the verticle thickener lie in the special device of the initial pulp supply to the thickener, its uniform distribution over the thickener's area, intensification of the water clarification process, uniform water collection from the whole area of the thickener and the thickened pulp removal.

The initial pulp is delivered to the thickener by the pipeline 1 to the central part 2 (Fig. 2).

In order to intensify the pulp clarification process, the thickener is provided with a thin-layer divider — shelf type medium, in the cells of which the laminar regime of the flow stream is maintained.

The thin-layer divider provides the solids particles settling in laminar stream of small depth, thus encouraging the rise of the thickener capacity and improvement of the clarified water quality. The hydraulic pulp load on the thickener makes up 40-45 cu.m./sq. m./h; suspended solids content with this load at the outlet is not more than 500 mg/l, when the initial concentration is 30000 mg/l. In this case the polyacrylamide dose by 100% product equals 1 mg/l.

The clarified water collection is achieved by the system of radial troughs 4, the design of which causes the uniform flow distribution and assures the thickener operation with the same specific load over the whole area.

The clarified water is derived by trough 5, and the thickened pulp under the hydrostatic pressure is removed by the pipeline 6.

Side by side with the highly efficient thickeners in the building for chemicals, the vortex disperser for preparing the polyacrylamide solution and large-capacious exchange packages are used.

The vortex disperser, being the central chain in the unit of polyacrylamide solution, comprises two technological operations:

— polyacrylamide dispersion by a turbulent fluid flow with the formation of the polydispersed suspension of a polymere in the solvent;

— obtaining the homogenous solution (without solvent water heating) with 0.05-0.1% concentration.

The vortex disperser operates in a continuous technological cycle, is easy to adjust and reliable in exploitation.

The apparatus design is presented in Fig. 3.

The high-viscous matter, passing through the piece of pipe 2 to the feeding chamber 1 goes through the perforated partition 2 to the dispersing chamber 3, where it is pulverized by the vortex flow, supplied under the pressure to the chamber 3 through the tangential piece of pipe 5. In chamber 3 the polymer dispersion in the liquid takes place. Further the flocculant dissolution process occurs in the vortex flow. The ready polyacrylamide solution is derived through the piece of pipe 4. The proposed disperser design provides the uniform supply of polyacrylamide over the whole area of the partition, that is practically impossible to be obtained in known constructions with the vertical arrangement of perforated surfaces.

The new flow diagram of processing the large quantities of polyacrylamide in vortex disperser decreases considerably the capital investments for the construction of the building for chemicals, reduces the manual labour, makes the operation simple and excludes from the technology the hot water use for a flocculant dissolution.

An automatic control of the pulp thickening process and chemicals supply is carried out by the control of polyacrylamide solution concentration according to the turbidity of the clarified water. Such a control system makes it possible to save up to 10% of polyacrylamide and improve the process of pulp clarification and thickening.

One of the new trends in the field of pulp thickening is the research on electromagnetic flocculation of the pulp prior to its clarification in thickeners. Preliminary data demonstrate the high efficiency of this method, which allows to reduce sharply or exclude at all the use of polyacrylamide from the technology.

Introduction of new decisions of pulp thickening at one of the objects made it possible to reduce capital investments by 3400 thousand roubles and operation expenditues — by 1830 thousand roubles.

According to the project of our Institute at one of the metallurgical plants the construction of facilities for cinder extraction from sewage of the rolling mill with the use of magnetic flocculation is being carried out (fig. 4).

Magnetic flocculator consists of cassetes with the magnetized ferritobarium washers.

In the flow diagram the magnetic flocculator 3 is installed prior to the secondary settling tanks 5 in supplying trough 1.

Passing through the flocculator, the cinder, entering the composition of sewage, is magnetized and enlarged. Flows with the enlarged cinder floccules are delivered from the supplying trough to the secondary settling tanks 5 through distribution system 4.

Secondary horizontal settling tanks are equipped with the scraper mechanism 6 for rabling the cinder to the sump 7 and collecting the oil, floating to the surface, into the trough 8.

The clarified sewer liquid from the secondary settling tanks is diverted by trough 9 for the reuse.

Cinder from the secondary settling tanks arrives at the sump 7, from where it is delivered by the gantry crane, supplied with the grab, to the bunker 11 for dewatering. Dewatered cinder by the railway transport is sent to the mill of clodding and briquetting and then it is utilized.

Oil, collected from the water surface of the secondary settling tanks is diverted to the oil pumping station 13 by trough 8, and after the preclarification it goes back to the rolling shop.

Secondary horizontal settling tanks are composed of sections in 11 x 33 m size. The load per section of the settling tank is 650 cu.m/h.

Application of the large-sized secondary settling tanks with the dispersed water inlet and preliminary magnetic flocculation allowed us to shorten the duration of the settling and to increase the load for settling tanks to 30%, keeping the clarification effect to 50-100 mg/l of suspended solids, with the initial cinder content of 400-500 mg/l.

For sewage treatment from one of the enterprises of oil-chemical industry the diagram is developed, which provides the preseparation of oil products and oil mud with the initial concentration of 2-5 g/l, and settling on oil separators and settling ponds, followed by more thorough treatment on quartz filters. Filters are demonstrated in Fig. 5.

Filter's media consists of a sand layer with 2-0, 75 mm coarseness, 1,2 m height, some layers of gravel with 2-32mm coarseness and 1,0 m total height.

Filtration takes place from bottom to up with 5,0 m/h rate. Due to the large capacity of the filter, the filter-cycle duration constitutes 2 days. The oil products contents in sewage after filtration decreases from 70-80 to 25-30 mg/l. Exploitation demonstrated filter's operation efficiency.

Filters regeneration is produced by treated sewage in two stages, applying cold and hot water with air blowing.

Due to the complicated conditions of regeneration, the Institute at present is carrying out the work on introducing the more capacious and easily regenerated media.

In order to improve the treatment efficiency and have the possibilities for the following use, the sewage, coming from the works are subdivided into separate flows:

- process and storm flows — the main bulk of sewage, polluted by oil products only. After treatment these flows are supplied back for the application in the system of the process water line;
- salt-containing and other flows polluted, besides oil products, by salts (chlorides, sulphates, sulphides and others). These flows are delivered for the additional biological treatment, and, when treated to the rate required by the sanitary and fish industry standards, they are diverted to the reservoir.

We have considered the questions of mechanical sewage treatment of some more watercapacious fields of industry with their reuse in production processes, as well as the utilization of the sludge of metallurgical enterprises.

Alongside with flows and water treatment our Institute is actively developing technological processes for the purpose of maximum reduction of pollution found in sewage and decreasing the specific water consumption per unit of production.

The subsequent improvement of mechanical treatment together with other treatment methods will make it possible to solve important problem of the most efficient use of water resources.

The Symposium conduction provides a means for a wide exchange of experience in achieving the common task to protect the nature and environment.

Thank you for attention.

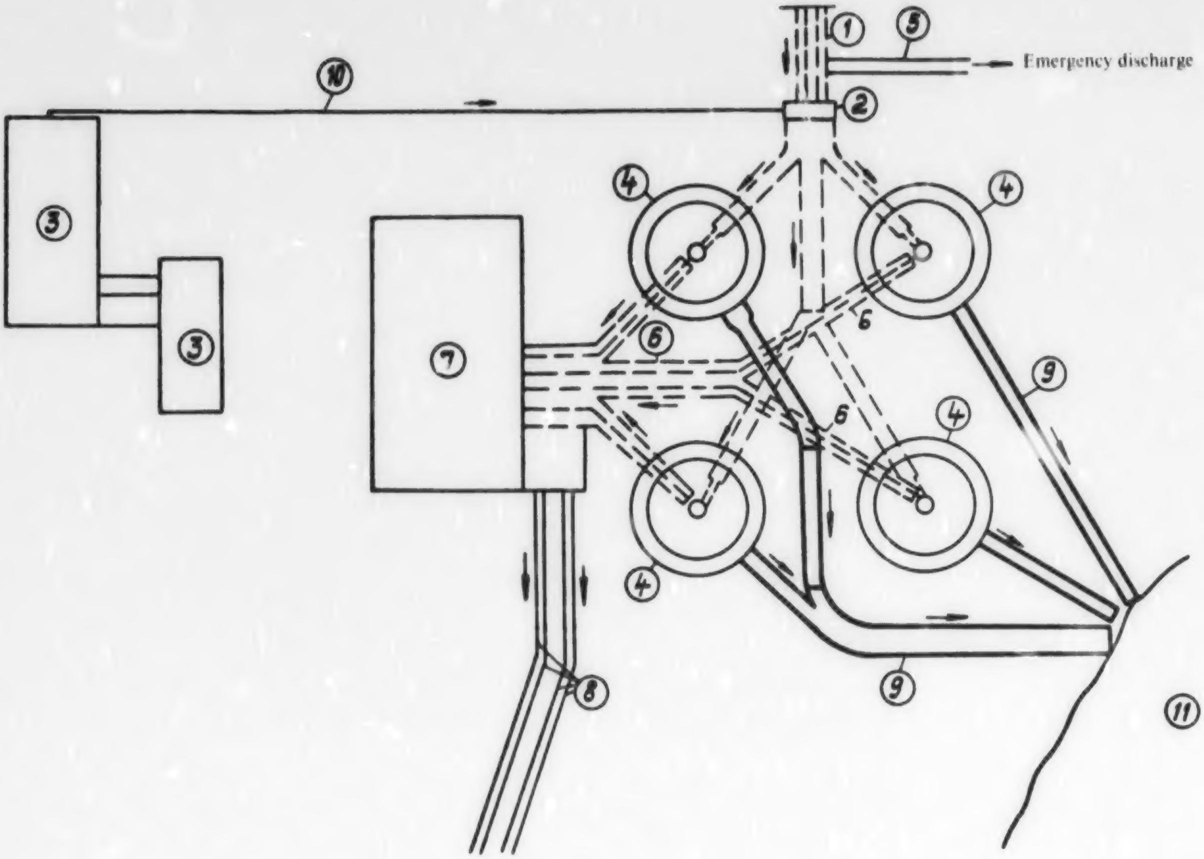

1
5
Emergency discharge
10
2
3
3
4
4
7
6
6
6
4
4
9
9
8
11

**Figure 1.**

**Flow Diagram of Pulp Thickening**

1. Trough, supplying hydromixture
2. Distribution chamber-separator
3. Building for chemicals
4. Thickener
5. Trough of emergency discharge
6. Piping of thickened pulp
7. Pulppumping station
8. Pressure pulp pipings
9. Troughs of clarified water
10. Chemicals pipings
11. Pond of recycle water supply

Clarified water
Initial pulp
Thickened pulp

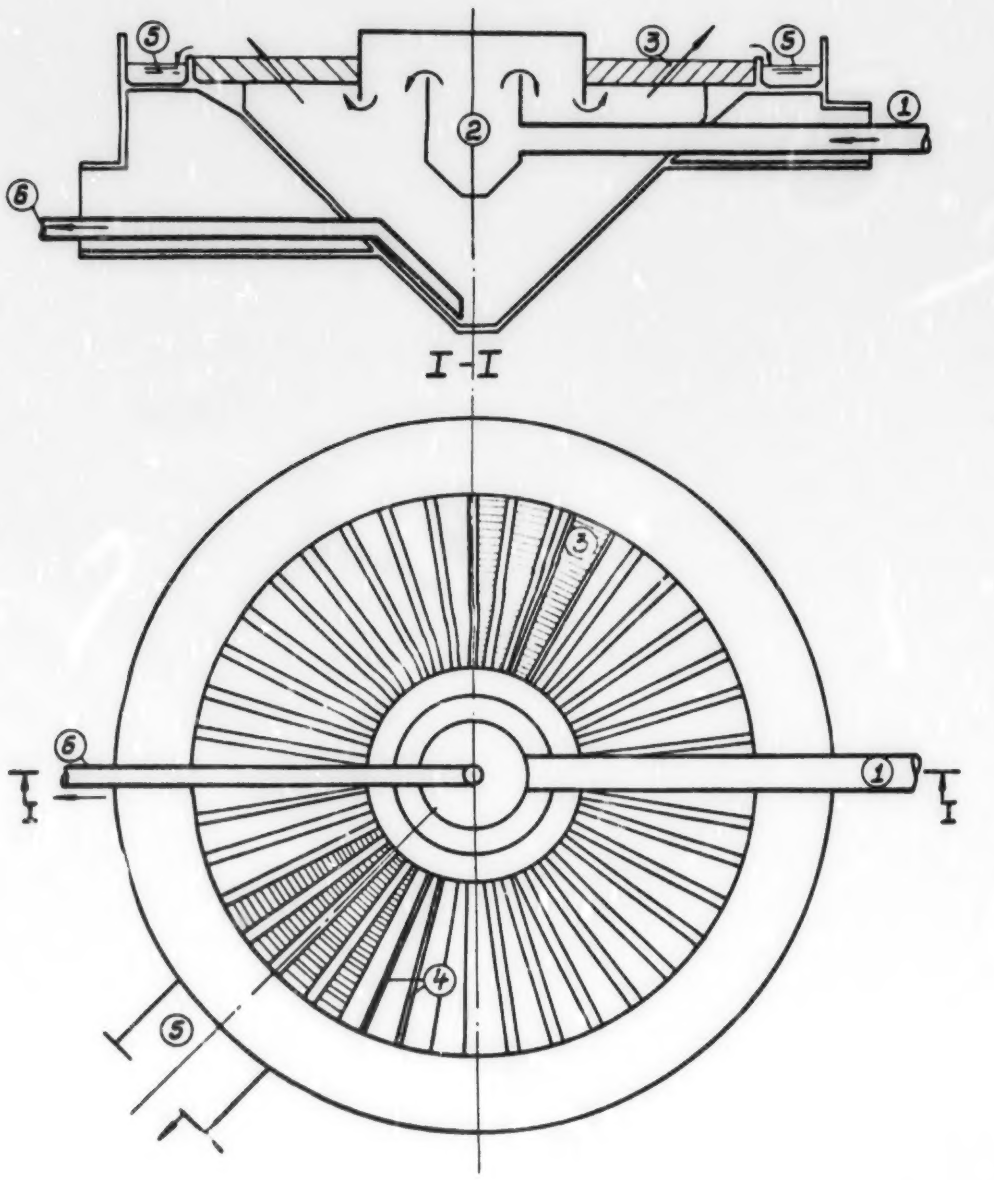


Figure 2.

**Vertical Thickener with Shelf-type Medium**

1. Supplying piping
2. Central part
3. Thin-layer shelf type medium
4. Radial collecting troughs
5. Trough, diverting clarified water
6. Piping of thickened pulp derivation

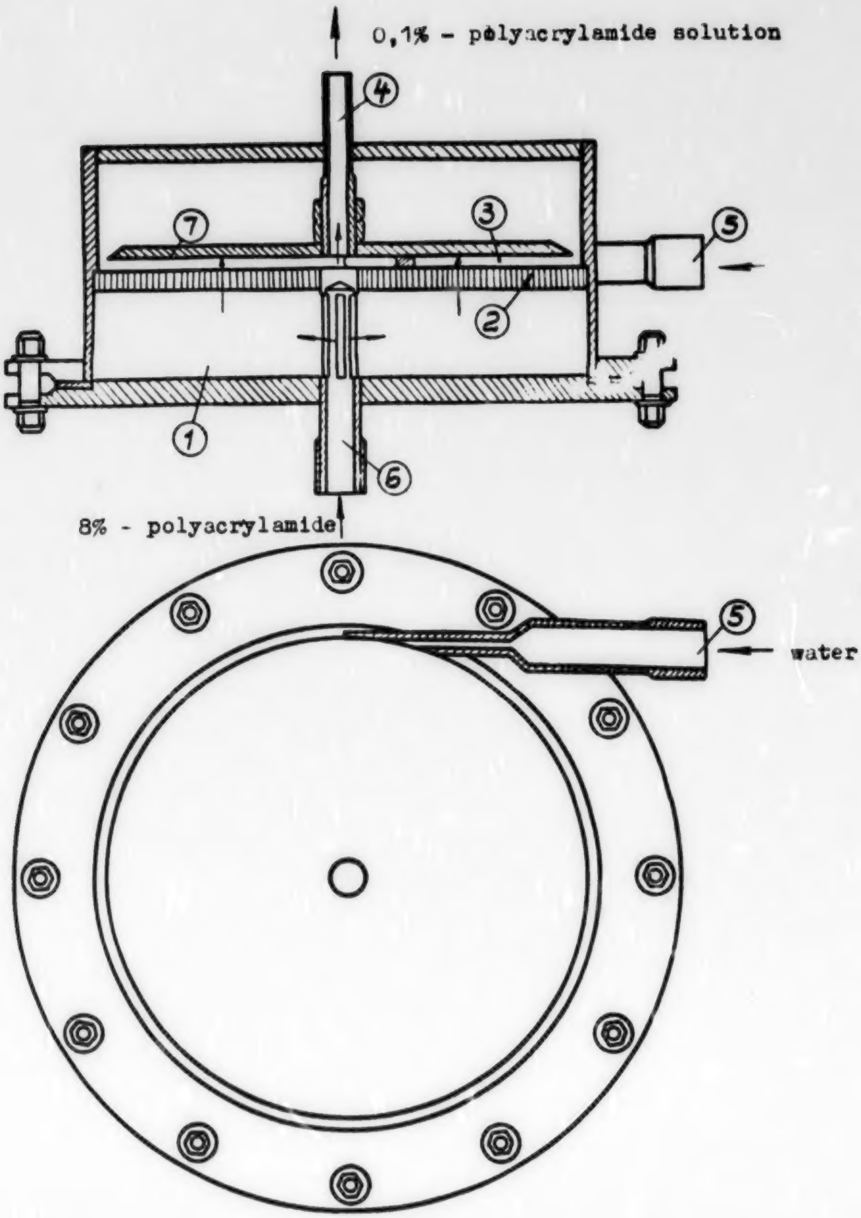
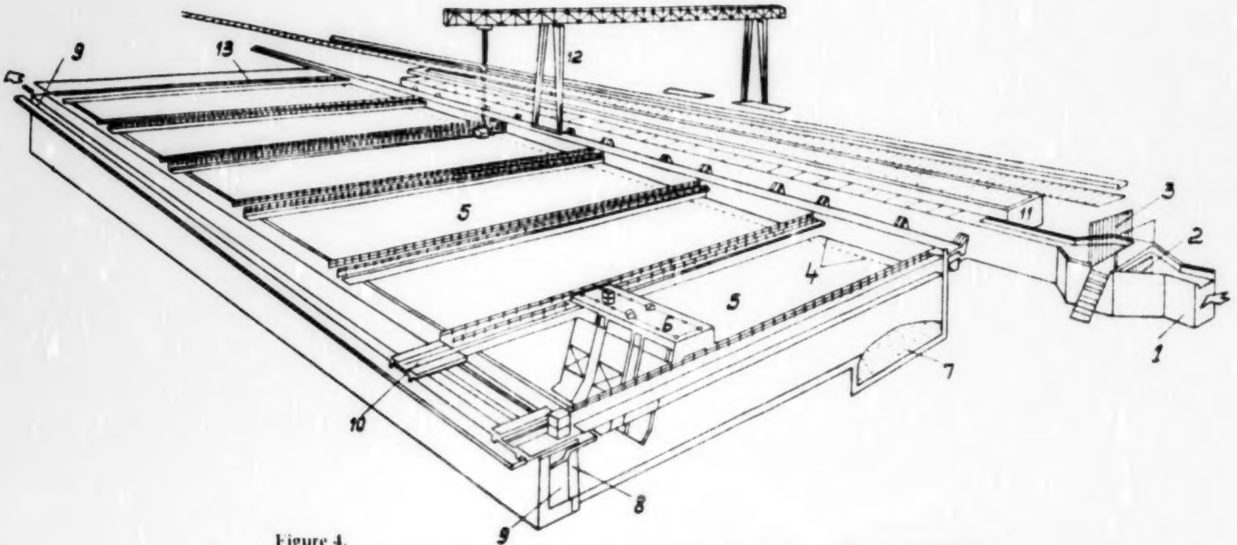

0,1% - polyacrylamide solution
4
7
3
5
2
1
6
8% - polyacrylamide
5
water

**Figure 3.**

**Vortex Disperser**

1. Supplying chamber
2. Perforated partition
3. Dispersing chamber
4. Piece of pipe, diverting polyacrylamide solution
5. Tangential piece of pipe of water delivery
6. Piece of pipe, supplying 8% polyacrylamide solution

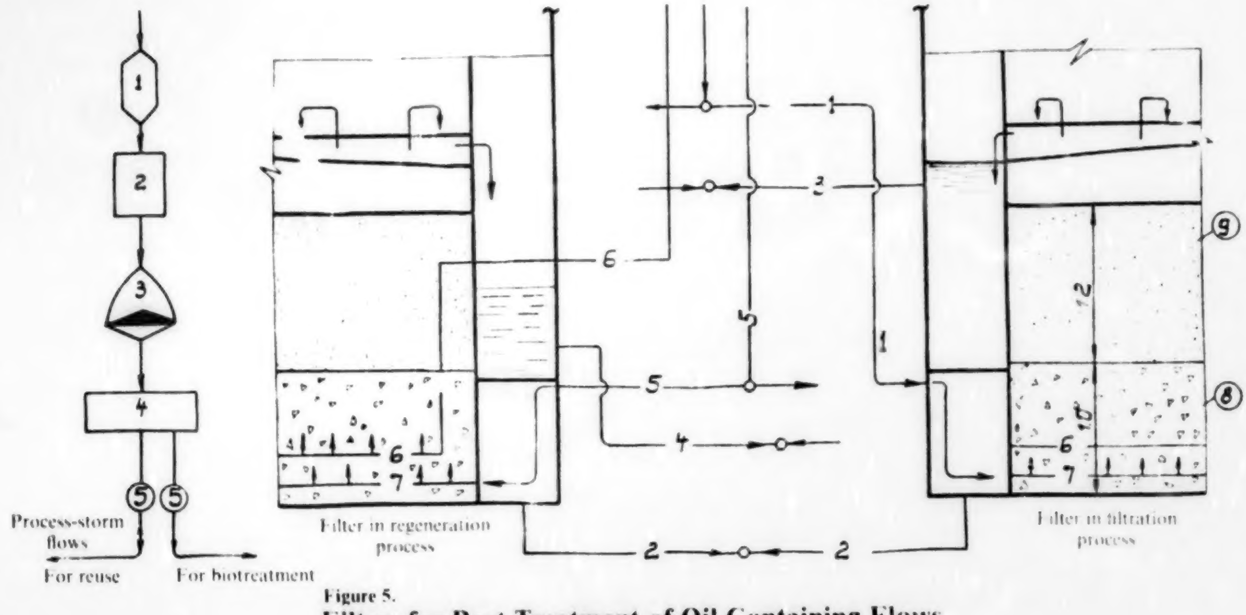


9
13
12
5
5
4
6
3
2
1
7
10
8
9
11

Figure 4.

**Secondary Horizontal Settlers with Magnetic Flocculation Chamber for Cinder Containing Sewage Treatment**

1. Delivering trough
2. Screen
3. Magnetic flocculator
4. Water distribution pipes
5. Secondary horizontal settlers
6. Scraper truck
7. Cinder sump
8. Oil diverting trough
9. Clarified water trough
10. Transborder truck
11. Sludge dewatering bunker
12. Gantry crane
13. Oil pumping station



1
2
3
4
5
5
Process-storm flows
For reuse
For biotreatment
1
2
6
5
4
1
2
2
6
7
Filter in regeneration process
9
12
8
10
6
7
Filter in filtration process

Figure 5.

**Filters for Post Treatment of Oil Containing Flows**

1. Grit chamber
2. Oil separator
3. Ponds
4. Filters
5. Tank and pumping station of filtered water

1. Sewage supply to filters
2. Filters emptying
3. Filtrate derivation
4. Wash water derivation
5. Wash water supply
6. Air piping
7. Drainage
8. Gravel medium
9. Sand medium

# The Swirl Concentrator for Treating and Regulating Sewered (Separate and Combined) and Unsewered Flows

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*February, 19*

## Introduction

Intensive studies to develop and demonstrate a new device called the swirl concentrator, for treating and regulating sewered and unswered wastewater flows were conducted under the general supervision of the U.S. Environmental Protection Agency's (EPA) Storm and Combined Sewer Technology Program, Municipal Environmental Research Laboratory, Cincinnati, Ohio. As a result, swirl devices are proving to be highly valuable and innovative tools for the nation's efforts to clean up pollution of its water resources.

The swirl concentrator has been developed following demonstration of a vortex combined sewer overflow regulator in Bristol, England, by Smission[1] who noted that the device permitted flow treatment by solids separation in addition to functioning as an overflow regulator. Swirl concentrators achieve removals of suspended solids by rotationally induced forces causing inertial separation in addition to vertical gravity sedimentation in relatively short detention times. Aside from its short detention, other advantages, such as low power and maintenance requirements are afforded by the fact that it is a static, non-mechanical device. Originally developed as combined (storm and sanitary) sewer overflow (CSO) regulators,[2,3] the concept has been refined and extended to selective grit removal,[4,5] attainment of primary removal efficiencies,[6] and erosion control.[7]

Untreated storm overflows from combined sewers are a substantial water pollution source during wet-weather periods. There are roughly 15,000 to 18,000 CSO points in the USA that emanate from 40% to 80% of the total organic load in these municipalities during wet-weather flow periods. It has been estimated that on a national level the expenditure for CSO pollution abatement would be more than $10 billion.[8,9,10]

In considering wet-weather pollution abatement, attention must first be directed to control of the existing combined sewerage system and replacement or stricter maintenance of faulty regulators. Consulting and municipal engineers will agree that regulator mechanical failures and blockages persist at the overflow or diversion points resulting in unnecessary by-passing, a problem also during dry weather. Malfunctioning overflow structures, both of the static and dynamic varieties, are major contributors to the overall water pollution problem.

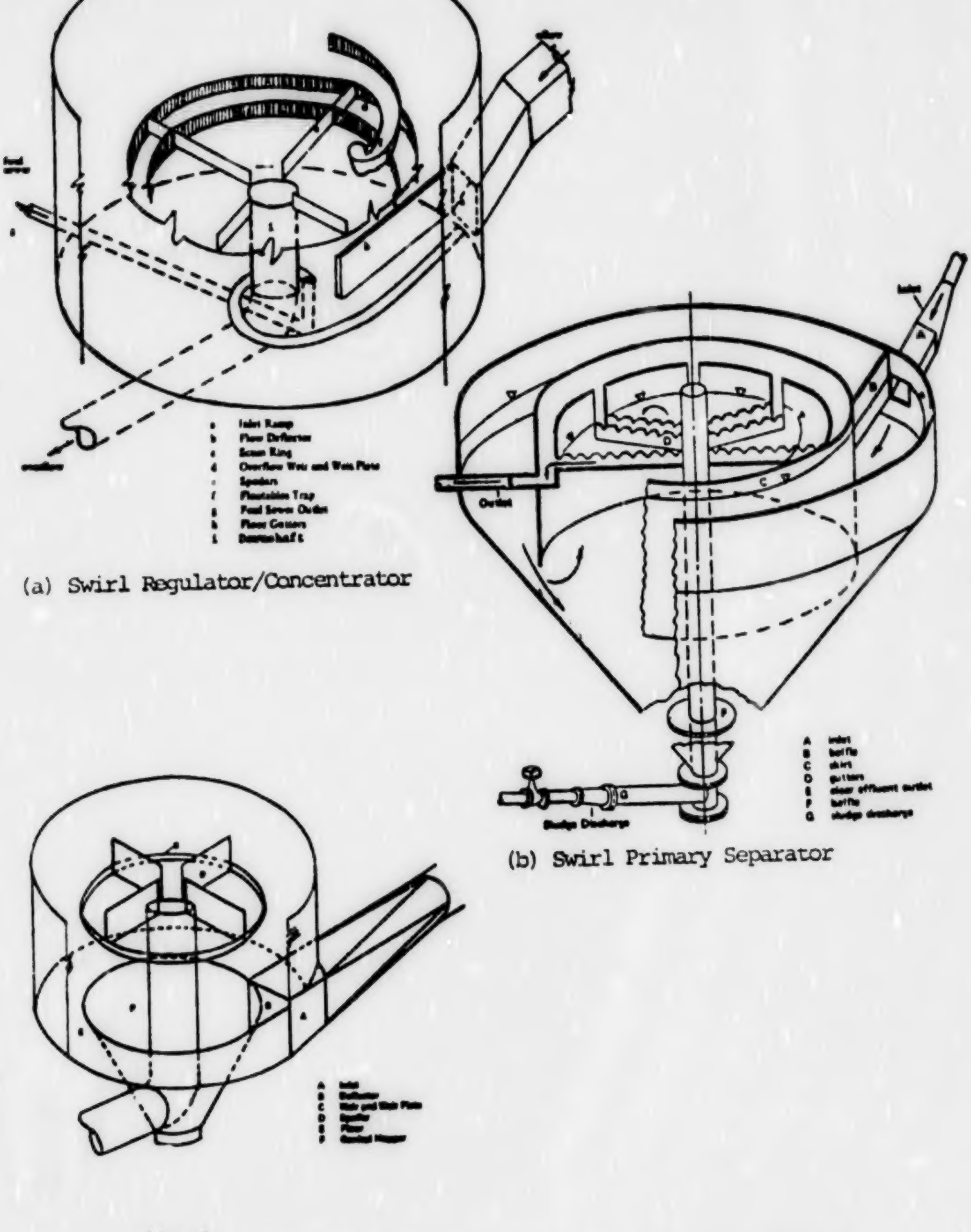
The practice in the USA of designing regulators exclusively for flowrate control or diversion of combined wastewaters to the treatment plant and overflow to receiving waters must be reconsidered. Sewer system management that emphasizes the dual function of CSO regulator facilities for improving overflow quality by concentrating wastewater solids to the sanitary interceptor and diverting excess storm flow to the outfall will pay significant dividends. A new phrase has been coined, the "two Q's," to represent both the quantitative and qualitative aspects of overflow regulation. Regulators and their appurtenant facilities should be recognized as devices which have the responsibility of controlling both quantity and quality of overflow to receiving waters, in the interest of more effective pollution control. The swirl concentrator should definitely be considered when combined sewer systems are upgraded and improved regulators are constructed to reduce the impact of overflows on receiving water quality.

It is for these reasons that EPA's initial swirl research and development efforts placed emphasis on design of the regulator/concentrator. Subsequent studies evaluated various swirl device alternatives such as the degritter, primary separator, erosion control device, etc. The following sections describing the basic principle, design characteristics, and model studies involve the *swirl regulator/concentrator*. It is hoped, since the various swirl devices are basically similar, that an appreciation for all of them can be obtained in this manner.

## Basic Principle

The swirl device differs from a sedimentation tank in that it utilizes the differences in inertia between particles and liquid as well as gravitational forces to effect solids-liquid separation.

Influent flow from the combined sewer is introduced tangentially to a circular chamber. The kinetic energy of the incoming sewage is guided by a vertical deflector that makes the flow take a "long path" around the chamber. This is the so-called primary current and is readily visible. In any flow around a bend, a secondary current is introduced to make the surface portion of the liquid flow outward from the center and the bottom portion flow toward the center. The secondary current that acts in the swirl device is similar to the current observed in rivers that makes the stream erode its outer bank and deposit sediment on its inner bank. Because of the effects of boundary friction, the water near the surface flows faster than the water near the bottom. The secondary current carries solids to the center, just as a river


inflow
foul sewer
overflow
a Inlet Ramp
b Flow Deflector
c Scum Ring
d Overflow Weir and Weir Plate
e Spoilers
f Floatables Trap
g Foul Sewer Outlet
h Floor Gutters
i Downshaft
inlet
Outlet
Sludge Discharge
A inlet
B baffle
C skirt
D gutters
E clear effluent outlet
F baffle
G sludge discharge
A Inlet
B Deflector
C Weir and Weir Plate
D Spoiler
E Floor
F Conical Hopper

(a) Swirl Regulator/Concentrator

(b) Swirl Primary Separator

Figure 1.

Isometric Configurations of Swirl Device in Three Applications deposits sediment on the inner bank. Thus, most of the settleable solids and grit that are forced down (by gravity) and outward toward the perimeter (by inertial force) are then swept inward by the secondary current to the foul (concentrate) orifice through which they exit for further treatment (Figure 1)). The larger volume of liquid, which should now be relatively clear of solids, is relieved of its floatable matter by a trap and passes over the circular overflow weir and plate for additional treatment or discharge directly to the receiving water.

The swirl device regulates flows by a central circular weir and bottom orifice which is basically the same as the common static flow regulator that operates by the dam and orifice principle. During low dry-weather flows, the entire sewage flow is guided along a gutter in the bottom and goes directly to the interceptor, which conveys it to the treatment plant.

During higher-flow storm operation, it separates solids as described above. The low-volume, high solids concentrate resulting from the swirl action is diverted via an orifice at the end of the bottom gutter to the interceptor, and the clear, high-volume supernatant overflows the central circular weir. This liquid can be further treated and discharged into the receiving waters, or, depending on quality requirements, directly discharged into the receiving waters. Provisions can also be made for storage and subsequent pumping of this relatively clear liquid to the sanitary sewage treatment plant during low-flow, dry-weather periods. This method thus allows the maximum treatment possible but still protects the treatment plant from overloading. Such a system makes treatment possible at all times and prevents raw combined sewage from being passed directly to the receiving waters during periods of heavy flow.

## Development/Verification of the Swirl Principle

In order to develop the swirl principle and provide a design basis, mathematical and hydraulic modeling studies [2,4, 6, 7, 11] were conducted. These studies were conducted for EPA by the American Public Works Association (APWA).

Swirl device models were developed using synthetic materials simulating the particle size distributions and specific gravities of grit and organics found in domestic sewage, CSO's, and erosion laden runoff. The APWA studies resulted in a series of design curves relating anticipated performance to design capacity and other design parameters.

As will be discussed in a later section, the above models have been or are currently being verified in pilot and prototype facilities using actual sanitary sewage and CSO at Syracuse, New York[11] (prototype regulator concentrator), Denver, Colorado[5] (pilot degritter), Toronto, Canada[6] (pilot primary separator), Rochester, New York[12] (pilot degritter and primary separator), and Lancaster, Pennsylvania [2,4] (prototype regulator/concentrator [8, 9] in series with swirl degritter for foul concentrate[9]).

Structurally, swirl regulator concentrators, swirl degritters, and swirl primary separators incorporate distinctly different features. Some of these differences are illustrated in Figure 1. The selected configuration for each application was a result of consideration of hydraulic principles and testing of a variety of physical models. Differences should be noted in weir configurations, baffling and floor layouts. The units also differ in design features such as inlet velocities, $D_2/D_1$ (chamber diameter/inlet dimension) ratios, and $H_1/D_1$ (weir height/inlet dimension) ratios.

Performance results were scaled from model results to predicted prototype results by using Froude Law scaling relationships. Model-to-prototype conversion used the Froude number,

$$N_f = \frac{v^2}{gS}$$

for scaling of unit dimensions, where $N_f$ Froude number, $v$=velocity, $g$= gravity acceleration, and $S$=reference length.

Since v is equivalent to Q/A, where discharge, Q, and area, A, are a function of the square of the inlet dimension $D_1$,

$$N_f = f\,\frac{Q^2}{D_1 5}$$

Froude number scaling thus employs the relationship:

$$\frac{Q\ \text{model}}{Q\ \text{prototype}} = \left(\frac{D_1\ \text{model}}{D_1\ \text{prototype}}\right)^{5/2}$$

for scaling of hydraulic flows. Geometric similarity must be maintained between model and prototype. In addition, four fraction (% of flow containing concentrate) must be the same in prototype as in model.

In a similar manner, particle settling velocities were also scaled, using Froude Law relationships.
Since

$$N_f = f\,\frac{v^2}{S}$$

scaling of settling velocities employs the relationship

$$\frac{v_s^2\ \text{prototype}}{v_s^2\ \text{model}} = \frac{D_2\ \text{prototype}}{D_2\ \text{model}} = \lambda$$

where $D_2$=unit chamber diameter, $v_s$=particle settling velocity, and $\lambda$=scale factor

Since settling velocity is dependent on effective particle diameter and specific gravity, the studies employed synthetic materials to represent settling velocities in the model studies. These represented scaled-down settling velocities from prototype scale for expected particle size distributions and specific gravities, and importantly, enabled a constant conservative substance to optimize hydraulic model configuration.

## Swirl Design Characteristics

To be useful in coping with storm overflow pollution, the swirl unit must function under conditions of widely varying flow rates and solids contents. Thus, as implied above, the various elements of the chamber must be carefully designed. The isometric view of the swirl regulator/concentrator [Figure 1 (a)] may help to visualize the various special elements which are identified by small letters.

### Inlet Ramp

The inlet ramp [Figure 1 (a), a] introduces the incoming flow at the bottom of the chamber, thus allowing the solids a greater chance of being separated.

Inflow should be nonturbulent to prevent the solids from being carried directly to the overflow weir along with the water. However, there should be enough energy to force the water around the chamber. The floor of the inlet ramp should be v-shaped to allow for self cleaning during periods of low flow.

### Flow Deflectors

The flow deflector [Figure 1 (a), b] is a vertical, freestanding wall that is an extension of the interior wall of the inlet ramp. It directs the flow around the chamber, creating a longer path and a greater chance of solids separation.

### Scum Ring

The scum ring [Figure 1 (a), c] prevents floating solids from overflowing. It should extend at least 15.2 cm (6 in) below the level of the overflow weir crest and works by baffling floatables and preventing them from overflowing the weir until they reach the floatables trap.

### Overflow Weir and Downshaft

The overflow weir and weir plate [Figure 1 (a), d] allow the liquid that has passed through the chamber and is now free of most of its settleable and floatable solids to leave the chamber through a central downshaft [Figure 1 (a), i] and either be stored or bypassed to the river.

### Spoilers

The spoilers [Figure 1 (a), e] are radial flow guides that extend from the downshaft to the scum ring and are vertically mounted on the weir plate. They allow efficient and controlled operation of the swirl concentrator under overload conditions and prevent turbulence and vortex conditions that impede proper functioning.

### Floatables Trap

The floatables trap [Figure 1 (a), f] is a surface flow deflector that directs floatables under the weir plate for storage during wet-weather operation. When the liquid level in the chamber decreases after the rainfall, the floatables exit through the foul sewer outlet.

### Foul Sewer Outlet

The foul sewer outlet [Figure 1 (a), g] located on the floor of the chamber, is the orifice through which the dry-weather flow and storm-flow concentrate exit, via the interceptor, to the treatment plant. It is placed at the point of maximum settleable solids concentration and is designed to reduce the clogging problems that often incapacitate regulators.

### Floor Gutter

The primary floor gutter [Figure 1 (a), h] is the peak dry-weather flow channel connecting the inlet ramp to the foul sewer outlet to avoid dry-weather solids deposition.

## Modeling: Solids Separation Efficiencies

Actual combined sewage could not be used in the scaled-down hydraulic model that was constructed for initial development of the swirl regulator/concentration principle. Grit and settleable solids had to be simulated with gilsonite, a natural hydrocarbon that could be mathematically related to the various solids components. Floatables were simulated with pethrothene.

For a prototype, the predicted efficiencies were as follows:

For floatables with a specific gravity range of 0.90-0.96 and particle sizes between 5 and 50-mm, the chamber should remove 65 to 80 percent.

For grit with a specific gravity of 2.65 and particles larger than 0.3-mm, removal should be between 90 and 100 percent. Removal efficiencies decrease to about 75 percent for 0.2-mm particles and to less than 40 percent for 0.1-mm particles.

For settleable organic solids with a specific gravity of 1.2 and particles larger than 1-mm, the efficiency should range from 80 to 100 percent. This fraction represents 65 percent of the total amount of settleable solids in the design solids concentration. For the finer particles, removal efficiencies decrease to about 30 percent for 0.5-mm particles and to less than 20 percent for 0.3-mm particles.

The mathematical simulation of prototype efficiency indicated that the device will work well, up to 150 percent or greater of design flow.

Syracuse, New York (Prototype Swirl Regulator/Concentrator)

A 3.6 m (12 ft) diameter swirl CSO regulator was installed at the West Newell Street outfall in Syracuse, New York[13] (Figure 2). Design flood flow to the swirl device was based on maximum carrying capacity of the .61 m (24 in) diameter inlet combined sewer—33,687 m$^3$/day (8.9 mgd)—and a design flow for quality control, in accordance with scale model investigation of 25,738 m$^3$/day (6.8 mgd).

Tests indicate that the device is capable of functioning efficiently over a wide range (10:1) of CSO rates, and can effectively separate suspended matter at a small fraction of the detention time required for conventional sedimentation or flotation (seconds to minutes as opposed to hours by conventional tanks). At least 50 percent removal of suspended solids and BOD$_5$ were obtained. Tables 1. and 2. contain further treatability details on the Syracuse prototype. The capital cost of the 25,738 m$^3$/day (6.8 mgd) Syracuse prototype was $55,000 or $2/m$^3$/day ($8,100/mgd) and $2,470/ha ($1,000/ac) which makes the device highly cost-effective.

Denver, Colorado (Pilot Swirl Degritter)

A large 1.8 m (6 ft) pilot swirl device designed as a grit removal facility was tested by the Metropolitan Denver Sanitary District No. 1.[8] Figure 3 contains a suggested swirl degritter layout for above-the-ground installations.
It was found under testing performed on domestic sanitary wastewater, at times spiked with 0.25-mm dry blasting sand to simulate swirl regulator foul concentrate concentrations, that the swirl unit performed well. The efficiency of removing grit particles of 2.65 SG. and sizes greater than 0.2-mm was equal to that of conventional grit removal devices. Scaled up detention times for full size swirl units having volumes one tenth that of conventional tanks, were as low as 20 seconds, whereas detention times of one minute and greater are normal for conventional grit chambers.

The small size, high efficiency and absence of moving parts in the basic swirl degritter unit offers economical and operational advantages over conventional grit removal systems.
Toronto, Canada (Pilot Swirl Primary Separator)

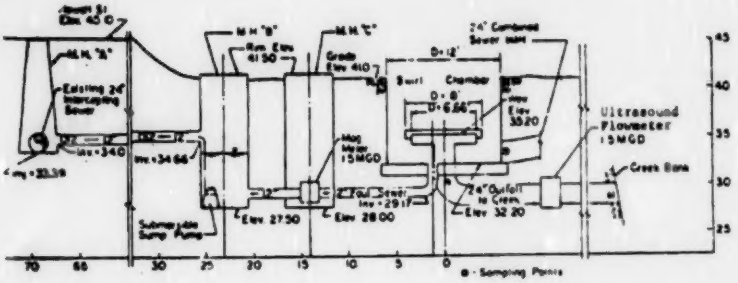

M.H. "A"
Existing 24" Intercepting Sewer
Inv. • 34.0
Inv. • 34.66
M.H. "B"
Rim Elev 41.50
M.H. "C"
Grade Elev 41.0
24" Combined Sewer
D = 12'
Swirl Chamber
D = 8'
D = 6.66'
Elev 35.20
Mag Meter 15MGD
24" Foul Sewer Inv. • 29.17
24" Outfall to Creek
Elev 32.20
Elev 27.50
Elev 28.00
Submersible Sump Pump
Ultrasound Flowmeter 15MGD
Creek Bank
45
40
35
30
25
70
60
30
25
20
15
10
5
0
• Sampling Points

Figure 2.
**Profile of Syracuse, NY Swirl Regulator/Concentrator**

Table 1.
**Swirl Regulator/Concentrator: BOD$_5$ Removal**

| | Mass Loading, kg | | | Average BOD$_5$ per storm, mg/l | | |
|---|---|---|---|---|---|---|
| Storm No. | Influent | Effluent | % Rem. | Inf. | Eff. | % Rem. |
| 7-1974 | 277 | 48 | 82 | 314 | 65 | 79 |
| 1-1975 | 97 | 30 | 69 | 165 | 112 | 32 |
| 2-1975 | 175 | 86 | 51 | 99 | 70 | 29 |

Table 2.
**Swirl Regulator/Concentrator: Suspended Solids Removal**

| | Swirl Concentrator | | | | | | Conventional Regulator | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mass Loading kg | | | Average SS per storm, mg/l | | | Mass Loading kg | | |
| Storm No. | Inf. | Eff. | % Rem.[b] | Inf. | Eff. | % Rem.[b] | Inf. | Under flow | % Rem.[a] |
| 02-1974 | 374 | 179 | 52 | 535 | 345 | 36 | 374 | 101 | 27 |
| 03-1974 | 69 | 34 | 51 | 182 | 141 | 23 | 69 | 33 | 48 |
| 07-1974 | 93 | 61 | 34 | 110 | 90 | 18 | 93 | 20 | 22 |
| 10-1974 | 256 | 134 | 48 | 230 | 164 | 29 | 256 | 49 | 19 |
| 14-1974 | 99 | 57 | 42 | 159 | 123 | 23 | 99 | 26 | 26 |
| 01-1975 | 103 | 24 | 77 | 374 | 167 | 55 | 103 | 66 | 64 |
| 02-1975 | 463 | 167 | 64 | 342 | 202 | 41 | 463 | 170 | 34 |
| 06-1975 | 112 | 62 | 45 | 342 | 259 | 24 | 112 | 31 | 27 |
| 12-1975 | 250 | 168 | 33 | 291 | 232 | 20 | 250 | 48 | 19 |
| 14-1975 | 83 | 48 | 42 | 121 | 81 | 33 | 83 | 14 | 17 |
| 15-1975 | 117 | 21 | 82 | 115 | 55 | 52 | 117 | 72 | 61 |

[a] For the conventional regulator removal calculation, it is assumed that the SS concentration of the foul underflow equals the SS concentration of the inflow.

[b] Data reflecting negative SS removals at tail end of storms not included.

A study[6] was conducted to determine if the swirl concentrator principle could be used to provide primary treatment to sanitary sewage, CSO, and stormwater. In comparison the swirl regulator concentrator provides a coarser pre-treatment. Initially a 0.9 m (3 ft) diameter hydraulic model and a mathematical model were used at the LaSalle Hydraulic Laboratory, Ltd., LaSalle, Quebec, Canada to arrive at a design configuration and basis.

The hydraulic model studies were based on synthetic solids made of Amberlite anion exchange resin IRA-93, which was considered to properly simulate actual solids in sanitary sewage flows.[11] The design criteria were based on Froude Law scale up. The design was then tested on a pilot 3.7 m (12 ft) diameter installation with real sewage at Metropolitan Toronto's Humber wastewater treatment plant, Toronto, Canada.

The pilot unit was tested at a design flow of 1,137 $m^3$/day (0.3 mgd) and at 1,700 $m^3$/day (0.45 mgd). The results of the tests indicated that the unit performed as effectively (40 percent suspended solids removal) as conventional settling basins at the Humber wastewater treatment plant operating at an overflow rate of 81.46 $m^3$/day/$m^2$ (2,000 gal/day/$ft^2$) with 1.06 hours detention time. The detention time in the swirl separator was 0.34 hours at an overflow rate of 108 $m^3$/day/$m^2$ (2,650 gal/day/$ft^2$) and 0.23 hours at an overflow rate of 162 $m^3$/day/$m^2$ (3,980 gal/day/$ft^2$), respectively for the two above mentioned capacities. Swirl detention times are calculated to include the sludge hopper to provide a size comparison with conventional tanks. However, when the size of the unit is calculated for a full 60 percent suspended solids removal, the size and retention time becomes equal to that of the conventional unit (Figure 4).

The studies provided proof of the applicability of the swirl principle to the function of primary clarification and verified the design that was based

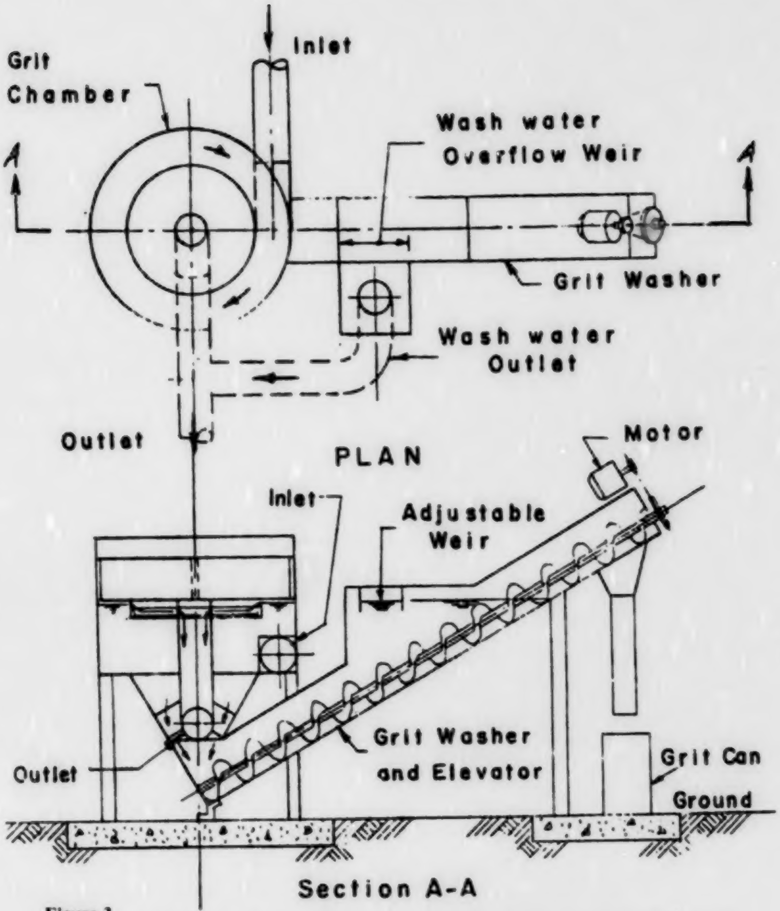


Figure 3.

**Suggested Swirl Degritter Layout for Above-the-Ground Installation with Inclined Screw Conveyor**

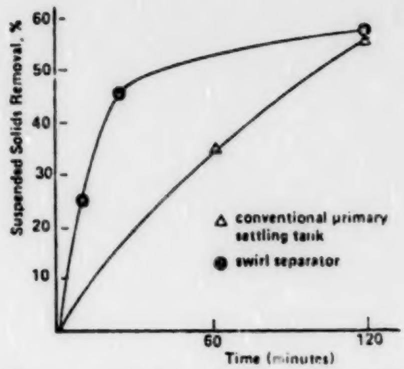


Figure 4.

**Comparison of Time to Achieve Primary Treatment: Swirl vs Conventional at Humber Wastewater Treatment Plant, Toronto, Canada**

on hydraulic model optimization. In a short detention period solids are deposited by inertial and gravity action and agglomeration mechanisms. Figure 4 indicates that removal efficiencies (less 50%) matched actual performance of conventional primary settling facilities in shorter periods of time at the Metropolitan Toronto facility. Importantly, in storm flow treatment application suspended solids will be heavier due to high sewer transport velocity and therefore will tend to separate more readily which favors swirl separation over sedimentation.

The basic advantages of the swirl clarification principle are that it requires: (1) less land than conventional sedimentation, and (2) no mechanical sludge collection equipment within the tank for the collection of settled solids in the sludge hopper. The latter advantage is partially achieved by providing a deep conical hopper over the entire floor area, thus, imposing an increase in costs.

The estimated construction costs of a swirl primary separator and a conventional primary settling tank both with capacities of 1893 $m^3$/day (0.5 mgd) are $275,000 and $138,000, respectively.

Annual operation and maintenance (O&M) costs are estimated to be less ($3000 less for 0.5 mgd (1983 $m^3$/day)) with the swirl unit. In urban areas where land is expensive the fact that the swirl requires one-half or less the surface area (accordingly to overflow rates) could make it competitive.

The engineer must consider the costs of construction, O&M, and land in a cost comparison figure. In the locations where land is at a premium it is advisable to compare the costs of smaller parallel swirl units with their lower O&M costs against those of conventional tanks.

### Rochester, New York (Pilot Swirl Primary Separator and Swirl Degritter)

Pilot plant treatability studies were undertaken to delineate the treatment alternatives available for control of CSO quality under the Monroe County, Division of Pure Waters, Rochester, New York.[12]

A major emphasis of the study was development of cost/benefit comparisons of processes that would allow primary-level treatment efficiencies. These processes were compared relative to their response to treating variable quality CSO's. Treatment of the highly concentrated first-flush overflow was of particular importance.

The pilot facilities included a swirl degritter and a swirl primary separator connected in series (Figure 5). The swirl degritter was 0.914 m (3 ft) in diameter and approximately 1.22m (4 ft) in total depth. During normal operations, the overflow from the degritter became the influent for the swirl primary separator. Provisions were also made, however, to allow the influent to bypass the degritter and go directly into the swirl primary separator. The swirl primary separator was 1.8 m (6 ft) in diameter and approximately 1.8 m (6 ft) in total depth including hopper. The inlet pipe diameter was 10 cm (4 in) and the outlet diameter was 7.6 cm (3 in).

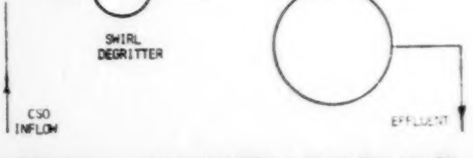


**Figure 5.**
**Schematic Diagram of Swirl Pilot Facility in Rochester, NY**

The swirl devices were tested at flowrates ranging from 0.9 1/sec to 4.4 1/sec (15 to 70 gpm). Using Froude Law scaling relationships, these translate to flows of 757 $m^3$/day to 3,785 $m^3$/day (0.2 to 1.0 mgd) for a 4.6 m (15 ft) diameter swirl primary separator and nominal overflow rates of 51 $m^3$/day/$m^2$ to 233 $m^3$/day/$m^2$ (1245 gpd/$ft^2$-5705 gpd/$ft^2$), respectively. Mathematical performance models were developed for each system relating suspended solids removal rates to influent flowrate (scaled by Froude number) and influent concentration.

These performance equations were compared to the design curves of the earlier development studies [2, 3, 4, 6] for swirl devices. Taking differences of particle size distributions into account, the Rochester data generally support the design presented by the earlier work.

### Lancaster, Pennsylvania (Prototype Regulator/Concentrator With Prototype Swirl Degritter In Series For Foul Concentrate)

The original swirl regulator/concentrator and degritter hydraulic model studies[2-4] were conducted for the Lancaster, Pennsylvania prototypes. The proposed prototype system being supported by an EPA demonstration grant,[12] is comprised of a 7.3 m (24 ft) main diameter swirl CSO regulator/concentrator with a smaller 2.4 m (8 ft) diameter swirl degritter in series to degrit the swirl regulator foul underflow prior to its entry to the interceptor pumping and sewer system (Figure 6). Upstream grit removal will prevent downstream pumping problems, sewer siltation, and treatment problems in the Lancaster sewerage system. The relatively clear swirl regulator/concentrator overflow will receive disinfection and go directly to the Conestoga River. This swirl system will serve a drainage area of 55 ha (135 ac).

The dry and wet-weather underflow

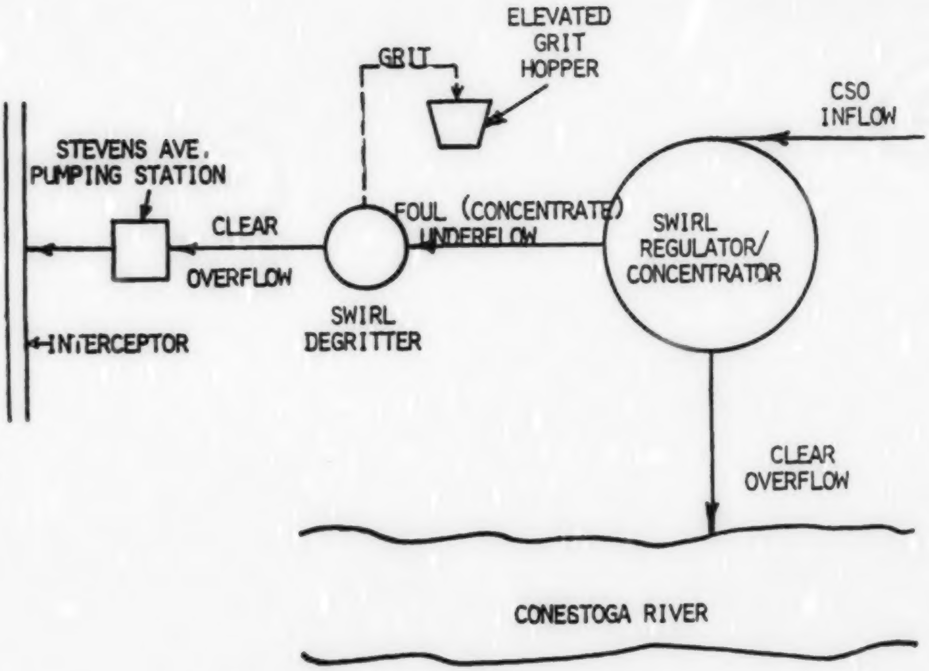


Figure 6.
**Schematic Diagram of Swirl Prototype System at Lancaster, Pennsylvania**

designed in accordance with downstream interceptor capacity is 12,200 m³/day (3.2 mgd). The underflow bypasses the swirl degritter during dry weather and is directed through the degritter when it is concentrated (1,000's of mg/1 suspended solids) during wet-weather flows.

The regulator was hydraulically designed to allow 1.1x10⁶ m³/day (291 mgd), the peak upstream inlet sewer capacity, without flooding. At the treatment design flow, of 97,650 m³/day (25.8 mgd) which represents a six in one year storm frequency, 65 percent suspended solids removal is estimated[8].

Hydraulic model studies[9] indicated that inflows much greater than 220,060 m³/day (58 mgd) would induce too violent a flowfield for effective treatment. Accordingly, an overflow relief weir is being provided along a section of the swirl chamber periphery to allow only that portion of the flows greater than 220,060 m³/day (58 mgd) to bypass treatment without upsetting the beneficial swirl currents which will continuously provide treatment to flows less than 220,060 m³/day (58 mgd).

The contractor's construction cost proposed for this system, which also contains degritter and control housing, a pilot microscreen, regulator roofing, and various appurtenances and research instrumentation is $669,000. The unit costs are $0.61/m³/day ($2,300/mgd) or $12,163/ha ($4,955/ac).

## The Swirl Concentrator as an Erosion Control Device

Erosion-sedimentation causes the stripping of land, filling of surface waters, and water pollution. Urbanization causes accelerated erosion, raising sediment yields two to three orders of magnitude from $3.5 \times 10^4$ - $10^5$ kg/km²/yr ($10^2$ - $10^3$ ton/mi²/yr) to $3.5 \times 10^6$ - $10^7$ kg/km²/yr ($10^4$ - $10^5$ ton/mi²/yr).[11] At the present national rate of urbanization, i.e., 1,620 ha/day (4,000 ac/day), erosion/sedimentation must be recognized as a major environmental problem.

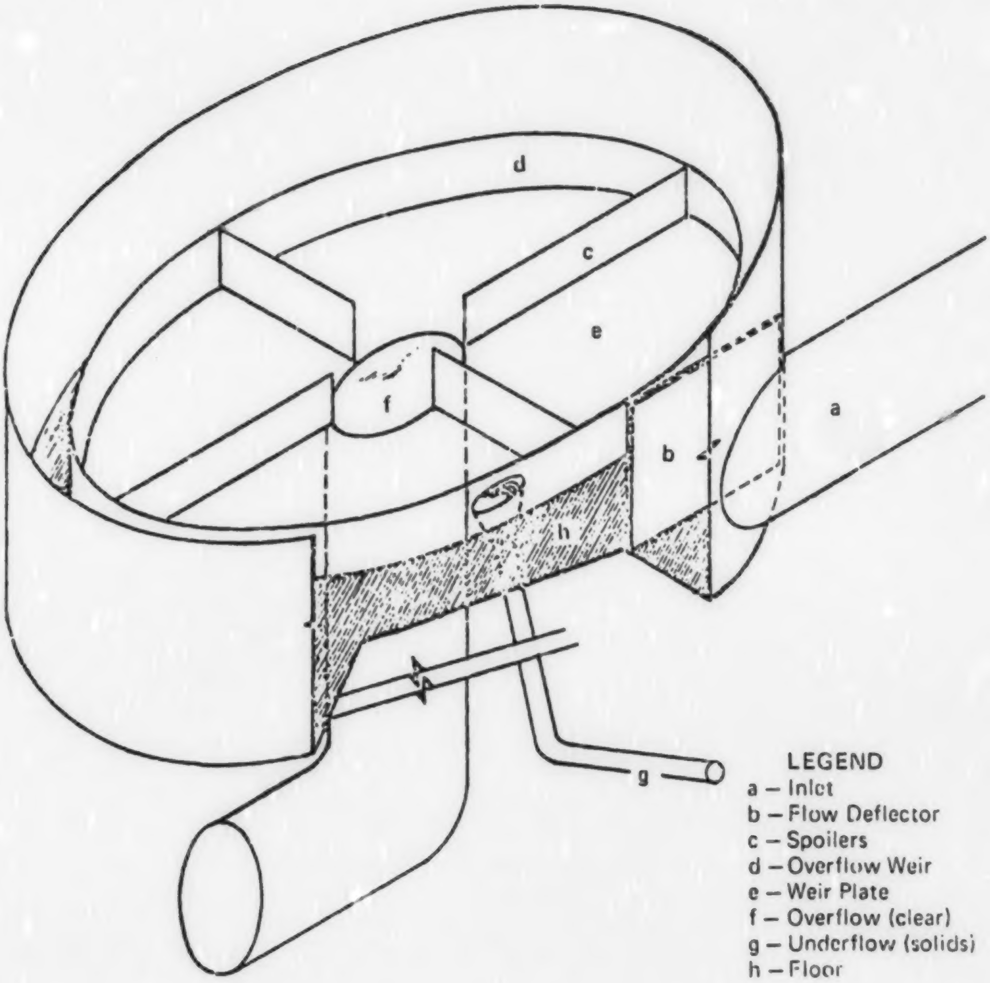

d
c
e
f
a
b
h
g
LEGEND
a – Inlet
b – Flow Deflector
c – Spoilers
d – Overflow Weir
e – Weir Plate
f – Overflow (clear)
g – Underflow (solids)
h – Floor

**Figure 7.**
**Isometric of Swirl Concentrator as an Erosion Control Device**

a. inlet
b. flow deflector
c. spoilers
d. overflow weir
e. weir plate
f. overflow (clear)
g. underflow (solids)
h. floor

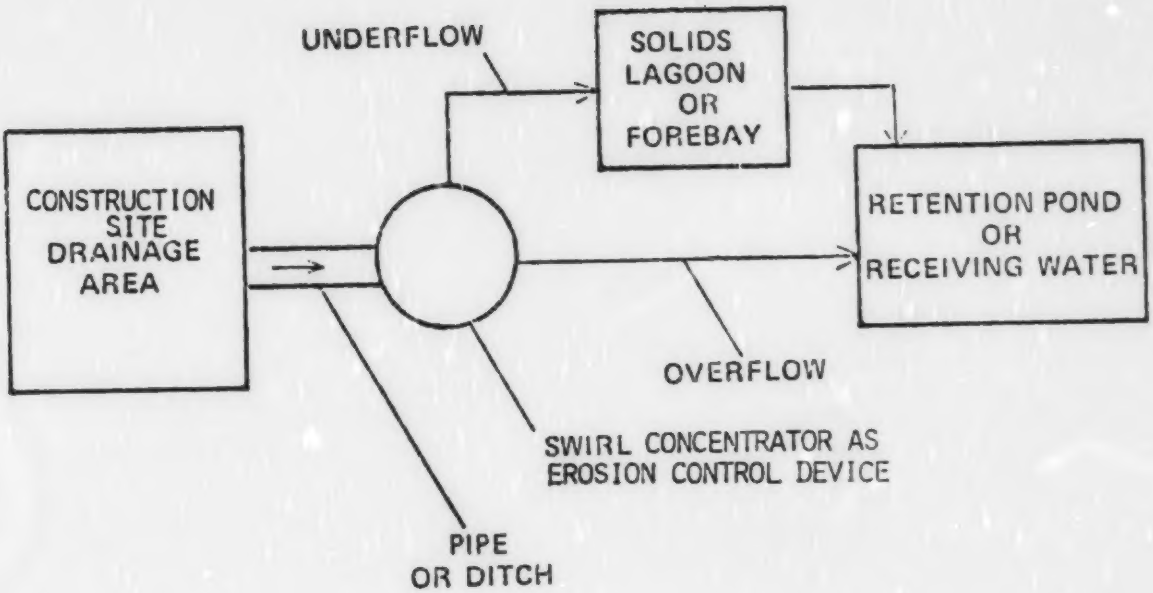

UNDERFLOW
SOLIDS LAGOON OR FOREBAY
CONSTRUCTION SITE DRAINAGE AREA
RETENTION POND OR RECEIVING WATER
OVERFLOW
SWIRL CONCENTRATOR AS EROSION CONTROL DEVICE
PIPE OR DITCH

Figure 8.
**Swirl Erosion Control Device Schematic Diagram**

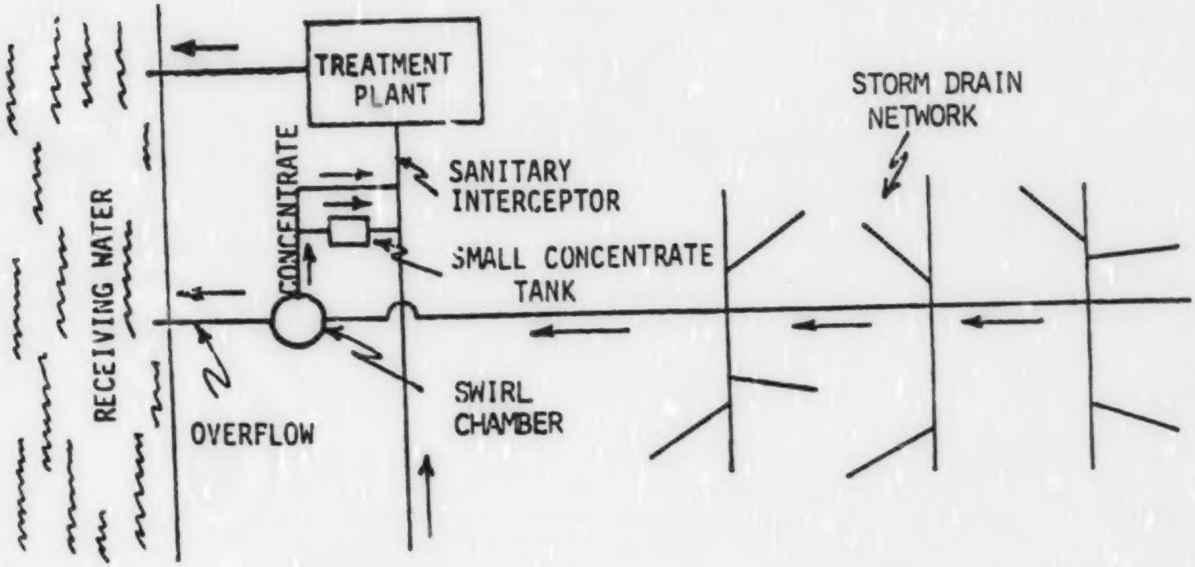

TREATMENT PLANT
CONCENTRATE
STORM DRAIN NETWORK
SANITARY INTERCEPTOR
SMALL CONCENTRATE TANK
RECEIVING WATER
SWIRL CHAMBER
OVERFLOW

Figure 9.
**Swirl Urban Storm Runoff Pollution Control Device Schematic Diagram**

The APWA under an EPA contract has developed a swirl erosion control device (Figure 7) which appears to be capable of performing an effective job of removing erosion particles from stormwater runoff at construction or other vulnerable sites. Such a swirl device can be rapidly and economically installed at points of erosion runoff by use of a conventional cattle watering tank having a 3.66 m (12 ft) diameter and a 0.9 m (3 ft) depth, fitted and equipped with a suitable inlet line, a circular overflow weir, a foul sewer outlet, and necessary interior appurtenances (Figure 7). This chamber could be readily disassembled, moved to another site, and reinstalled for the treatment of erosion runoff flows. If a permanent structure is desired, it can be fabricated out of concrete.

The de-silted, or clarified effluent could be discharged to drainage facilities and disposed of into receiving waters or other points of disposal or use. The collected solids could be discharged through the foul sewer outlet and entrained or collected at suitable points of erosion or for use for other predetermined purposes (Figure 8).

## The Swirl Concentrator as Urban Storm Runoff Pollution Control Device

Swirls similar to the CSO regulator variety can be installed on separate storm drains before discharge and the resultant concentrate can be stored in relatively small tanks since concentrate flow is only a few percent of total flow. Stored concentrate can later be directed to the sanitary sewer for subsequent treatment during low-flow or dry-weather periods, or if capacity is available in the sanitary interceptor/treatment system, the concentrate may be diverted to it without storage (Figure 9). This method of storm water control would be cheaper in many instances than building huge holding reservoirs for untreated runoff, and offers a feasible approach to the treatment of separately sewered urban stormwater.

## Potential Uses

The swirl principle may be employed anywhere it is desirable to remove solid particles from liquid flows. In the field of water pollution control this principle could relate to the degritting of sanitary and storm flows and to primary separation, sludge thickening, and the final clarification process. Because the swirl creates a defined mixing pattern it appears feasible to apply a form of the swirl for the simultaneous enhancement of chemical coagulation and disinfection while clarification of raw water for potable usage or wastewater is taking place. Other possible uses include various industrial processing.

Applications to relatively steady-state, dry-weather (municipal and industrial) flows may involve less arduous conditions of operation than does the CSO application. Both the hydraulic laboratory and the mathematical model investigations have indicated that solids separation efficiency may increase if the device operates under steady flow conditions.

Better efficiencies may also be achieved with two half-size chambers as opposed to one full-size unit. With two units operating in parallel, one chamber could be used for all flows lower than a predetermined design value, and the second could be used if the storm flow exceeded that value. This approach would provide better separation at both higher and lower flowrates. Another possibility is operating the units in series to improve solids removal by breaking a wide range of particle characteristics into narrower grain size and specific gravity bands.

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**P. I. Galanin**

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# Sewage Treatment of the City of Moscow

In view of the rapid rates of the industrial production development, the problem of environmental control and environment condition improvement, particularly water resources control is becoming more and more acute.

In solving this problem, of greatest importance is the act, issued by the Central Committee of Communist Party of the Soviet Union and Council of Ministers of the USSR—"On intensification of environmental control and improvement of utilization of natural resources," adopted in development of the law, approved by the Supreme Soviet of the USSR.

At present the development of measures of long-term and annual plans on environmental control and rational utilization of natural resources makes an integral part of the plans of national economy.

The most difficult in solving the problem of environmental control is the problem of water resources control in large cities with diversified industries, high concentration of transport facilities and housing and public building density.

Important work on environmental preservation, regeneration and condition improvement is conducted in our capital—the city of Moscow.

Preservation of rivers and water reservoirs is an indispensable condition, ensuring sanitary welfare of such a large city as Moscow.

In recent years large-scale work on the construction of large sewerage systems and treatment plants has been carried out and is being conducted in the city of Moscow. Hundreds of local industrial waste treatment plants have been commissioned.

The central sewerage system serves 98.5% of the city population. To the treatment plants with a total capacity of 4,230,000 $m^3$/day more than 4.3 mill $m^3$/day is fed and subjected to full biological treatment. Industrial wastes make up about 40% of the total municipal sewage.

The total length of channels, sewers and mains is more than 4500 km. The capacity of the sewage pumping stations is 6.5 mill $m^3$/day.
The sewage is subjected to full biological treatment ot five activated sludge plants of the following capacity ($m^3$/day):

| | |
|---|---|
| Kuryanovskaya plant — | 2,125,000 |
| Ljuberetskaya plant — | 1,500,000 |
| Ljublinskaya plant — | 500,000 |
| Tushinskaya and Zelenogradskaya plants — | 105,000 |

Basic average figures for sewage pollution and treatment quality, mg/1

| | Influent water | | Effluent water | | |
|---|---|---|---|---|---|
| Plant | SS | BOD | SS | BOD | DO |
| Kuryanovskaya | 195 | 176 | 10 | 10.2 | 5.8 |
| Ljuberetskaya | 185 | 208 | 10 | 10.2 | 4.2 |
| Ljublinskaya | 164 | 194 | 16 | 14.5 | 3.5 |
| Zelenogradskaya | 176 | 101 | 1.5 | 1.0 | 8.7 |

At the large activated sludge plants of the city of Moscow a two-stage sewage treatment scheme has been used: mechanical and biological. At present, a transition is being made to the three-stage treatment, using filters for polishing, with different types of granular filter beds.
High demands for better quality of effluents, discharged to the Moskva, have been called forth by the necessity to maintain sanitary conditions and self-purification processes of the river.

The Moskva is a low-capacity water reservoir, the natural discharge of the river at low-water being 13 to 15 $m^3$/sec. For the sanitation of the river, measures have been worked out and effected to supply it with water from the Moskva Canal at a rate of 31 $m^3$/sec.

The modern satisfactory condition of the river has been achieved both by ceasing the discharging of raw sewage and by a high enough level of activated sludge plant operation.
One of the most efficient plants is the Kuryanovskaya activated sludge plant (Fig. I).

The plant is one of the largest in the world. As far back as before World War II of 1941-45, the first unit was designed with a capacity of 750,000 $m^3$/day. The construction, interrupted by the war, was completed in 1950. In 1960 the capacity of the the plant was increased to I mill $m^3$/day.

In view of the rapid house building (120,000 flats are built in Moscow per year), systems for disposal of sewage and treatment plants are being constructed at increasing rates. In 1965 the Ljuberetskaya activated sludge plant with a capacity of 1.5 mill $m^3$/day was commissioned. In 1966 construction of the second unit of the Kuryanovskaya plant of 1.0 mill $m^3$/day was started. The plants were put into operation in 1971. At present the 3rd unit is being constructed with a capacity of 1.00 mill $m^3$/day, and 500,000 $m^3$ will be commissioned in 1977. Construction of the whole plant complex is to be completed in 1978.

The total capacity of the Kuryanovskaya plant will be 3,125,000 $m^3$/day, including 2 mill $m^3$/day of the plant for polishing biologically treated effluents. The facilities of the second unit of the plants are more advanced in relation to process and design; experience of construction and operation of the facilities has been widely used in many cities of the USSR.

Sewage treatment at the activated sludge plants is affected according to the classical scheme:

screens → grit chambers → primary settling tanks → aeration tanks → secondary settling tanks

## Mechanical treatment facilities

Screens for mechanical removal and grinding of the screenings intercepted are provided at the plants. The openings are 16 mm wide. 10-12.5 1 of screening are removed per 1000 $m^3$ of sewage. Moisture content—75-77%, ash content—6 to 9%. The ground screenings are pumped to the digestion tanks.

**Grit chambers**—vertical, horizontal, horizontal and aerated. 20 to 25 1 of grit are removed per 1000 $m^3$ of sewage. Moisture content—36-44%, ash content—72 to 80%, grit content—65-72%, grain size 0.25 mm—75%.

**Primary settling tanks** of radial type, diameters of the settling tanks—33, 40 and 54 m. At the second and the third units of the Kuryanovskaya activated sludge plant the settling tanks (diameter—54 m) are combined with preaerators.

Detention period—1.5 to 2.0 h, the percentage removal of suspended solids—45-65. $BOD_5$ removal—30-35%. Moisture content of the sludge—93-94%.

## Biological Treatment Facilities

At the Kuryanovskaya and the

Ljuberetskaya activated sludge plants four-corridor aeration tanks are used with separate regeneration of activated sludge. Aeration is through diffuser plates.

Air consumption—5.2-6.5 $m^3$ per 1 $m^3$ of sewage. Aeration duration—4.5-6.0 h. $\text{BOD}_5$ removal—91-92%; mixed liquor suspended solids in aeration tanks—1.2-1.5 g/1, in activated sludge regenerating tanks—4.5-5.5 g/1. Dissolved oxygen—6-7 mg/1.

**Secondary settling tanks** of radial type, diameters—33, 40 and 54 m. Detention period—2.0-2.2 h, activated sludge removal is by sludge scrapers.

## Tertiary Treatment

The solution of the problem of preventing the pollution of water reservoirs is tightly connected with the development of sewage treatment technology and finding ways for reuse and multiple use of effluent water in the systems for industrial water supply of industrial plants.

Three-stage and more than three-stage treatment, or the so called tertiary treatment, is more and more widely used. In the system of Moscow sewerage, tertiary treatment was first used on an industrial scale at the Zelenogradskaya activated sludge plant in 1965.

The construction of the tertiary treatment plant was necessitated by the protection of Skhodnya River, down the stream of which there are several ponds, including a pond for trout breeding; the river is being widely used for recreational purposes and by the population in the country places.

Average monthly figures for final effluent quality:

| | after biological treatment | after tertiary treatment |
|---|---|---|
| $\text{BOD}_5$ (mg/l) | 7.4 | 1.0 |
| Suspended solids (mg/l) | 11.0 | 1.5 |

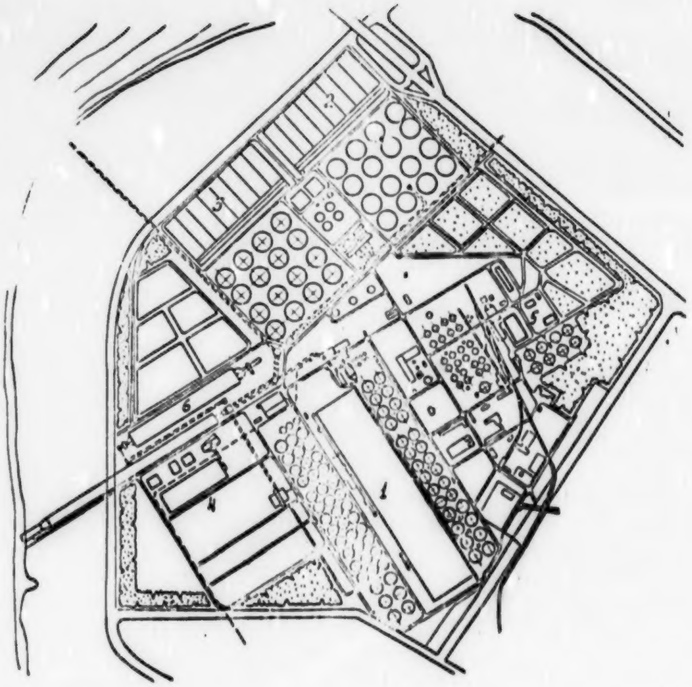

Figure 1.

**Plan of the facilities of the Kuryanovskaya activated sludge plant**

1. 1st unit of 1.0 mill $m^3$/day capacity
2. 2nd unit of 1.0 mill $m^3$/day capacity
3. 3rd unit of 1.0 mill $m^3$/day capacity
4. Tertiary treatment facilities of 2.0 mill $m^3$/day capacity
5. Sludge treatment facilities
6. Experimental facilities — 125000 $m^3$/day

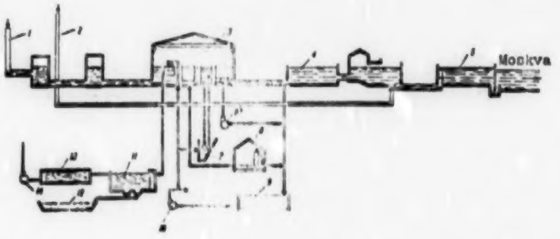

Figure 2.

**Flow sheet of tertiary treatment of the Kuryanovskaya activated sludge plant:**

1. feed conduit
2. emergency water discharge pipe
3. filter and drum screen building
4. outlet channel
5. contact channel
6. pumping station for filter washing
7. sand hopper
8. chlorinator house
9. polished water tank
10. polished water pumping station
11. grit chamber
12. sand drying bed
13. wash-water tank
14. wash-water pumping station.

The experience of tertiary treatment in the town of Zelenograd has been used at the Kuryanovskaya activated sludge plant, where 2 mill $m^3$/day will be subjected to tertiary treatment. (Fig. 2). At present the polished water is being used at several industrial plants of the town. In the future the industrial plants will be supplied with up to 5 $m^3$/sec of water for industrial purposes.

It is considered whether the polished water could be used for land irrigation and supplying water reservoirs with water.

The plant complex includes: rapid filters, consisting of a drum screen building, a filter building and a pumping station building for filter washing, a grit chamber, a wash-water tank, and a wash-water pumping station. Effluents are supplied by gravity to the tertiary treatment plant.

To remove coarse particles, drum screens are used with filter cloth, mesh size of 0.5 x 0.5 mm. Filters are of coarse grain type with a filtration area of 109 $m^2$. Filtration rate is 10 to 15 m/h.

Filters are washed with filtered water for 6 min. Wash rate is 18 1/sec.$m^2$. The pumping station is designed for simultaneous washing of two filters twice a day. The filtered water from the two filter sections enters the channels, flows by gravity to the contact channel, and then is discharged to the Moskva. While flowing to the water reservoirs the water is oxygenated by waterfall aeration. Wash-water from the filters passes through the grit chamber and enters the wash-water tank, from where it is pumped by the pumps, installed at the wash-water pumping station, to the primary facilities of the plant.

The tertiary treatment plant ensures effluent purification to a degree higher than that of the full biological treatment, and guarantees stable composition of the effluent, meeting the sanitary standards for water discharged to water reservoirs and for the industial water quality.

## Sewage Sludge Treatment

The activated sludge plants of the city of Moscow produce 19,000 to 20,000 $m^3$ of sludge per day with moisture content 96%. The sludge treatment is conducted by subsequent stages: digestion in aerobic digesters at thermophilic conditions (52°C), washing and thickening, coagulation, vacuum filtration and heat drying.

The charge dose of the digestion tanks in terms of actual moisture content is 15-18%. The steam from the boiler room enters the digestion tanks through the injection heaters. Steam consumption per 1 $m^3$ of sludge charged is 50 to 60 kg. Gas yield per 1 kg of volatile solids is 400 to 500 1.

The sludge is vacuum treated on drum vacuum filters -40-3 (diameter of the drum—3 m, filtration surface area—40 $m^2$). The average capacity of vacuum filters for 1976 was 22.8 kg/$m^2$/h using chemical doses of ferric chloride—3.7% and of lime—10% for sludge dry residue, with moisture content of the entering sludge—95.9% and moisture content of the cake—77-78%.

The sludge is heat treated in the dryers of drum type (diameter—3.5 m, length—18 m). The design temperature of the flue gases, produced by the combustion of fermentation gases of the digestion tanks in the dryer furnaces, at the inlet of the dryer is 800°C; the temperature of waste gases at the outlet is 250°C.

The waste gas is used for sludge heating in scrubbers.

Due to complex content of nitrogen, phosphorus, potassium, lime and microelements in the treated sludges, it is advisable to use them as organic and mineral fertilizers. 250,000 to 300,000 t/year of sludges (moisture content—65 to 75%) are taken out to the agricultural fields of the collective and state farms near Moscow after mechanical sludge dewatering and from the sludge drying beds.

## Prospects of Sewerage Development

In accordance with the General Plan for development of the city of Moscow, major trends have been defined in the field of disposal and treatment of sewage and contaminated surface run-offs.

The capacity of the Ljuberetskaya activated sludge plant will be increased to 2.5 mill $m^3$/day.

In 1985 the construction of the Pakhrinskaya plant will be started with a capacity of 4 mill $m^3$/day.

At present technical and economical basing is being developed for complex facilities of sewage sludge treatment.

By the design year (1990) the principal approach to the sewage treatment technology should change as to the process, ensuring the reduction of impurities in final effluents to a level which would not affect the development of natural processes in water reservoirs.

To meet this requirement the sewage treatment technology will involve high rate biological treatment processes using high MLSS.

Complex technological schemes will be further developed as well as methods for treatment of domestic and industrial wastes, with improved figures for the quality of treatment, relating to the removal of organics with poor biodegradation properties.

On the basis of research work being conducted, the most economic and efficient methods will be established for sewage treatment (physical and chemical, biological etc.)

The teritary treatment must ensure maximum reduction of all types of impurities, including organic matter, nutrients (nitrogen and phosphorus, oil wastes, synthetic surfactants, heavy metal salts etc.).

Natural ion exchange materials (vermiculite, phosphorite, perlite, diatomaceous earth etc.) will be widely used for filter beds.

There will be quite a new trend in the development of the system for disposal of the contaminated surface run-off. Provision is made for the combined system, in which contaminated surface run-offs will be conveyed together with domestic and industrial wastes.

By 1980 maximum possible extension of the traditional scheme will be completed, and after 1980 realization of means for the transition to the sewerage system of deep design will begin. Provision is made for the construction of intercepting sewers of a large diameter, running through loading centres of the sewerage areas, with pumping of sewage to the treatment plants.

Realization of planned specific measures for introducing the achievements of science and technology into the practice of sewage treatment and sludge treatment will allow to solve great problems in the field of control and rational utilization of water resources.

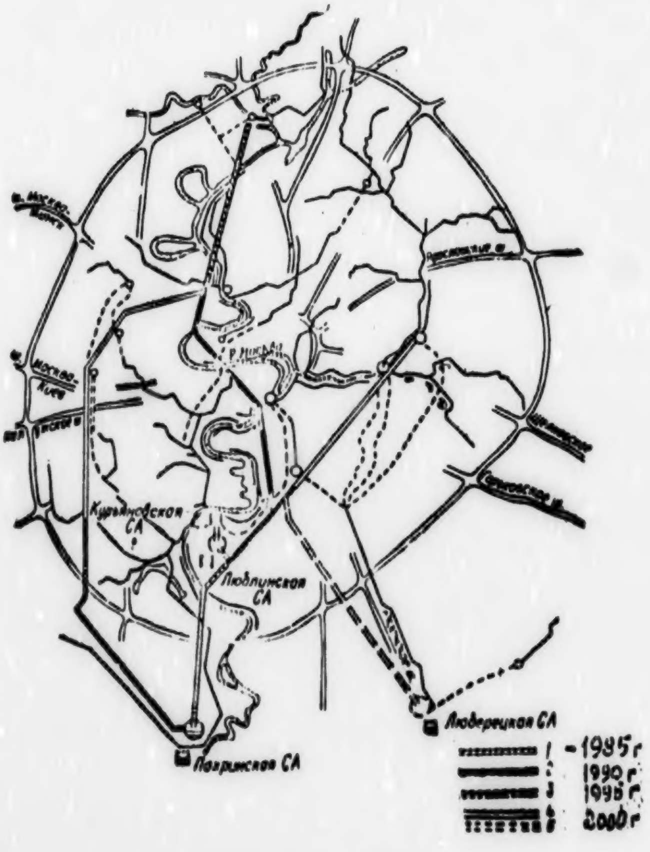

Figure 3.
**Scheme for long-term development of Moscow sewerage system.**

## Water Supply and Sewerage Administration of the city of Moscow

## List of slides of sewage treatment facilities of the city of Moscow

*(to paper "Sewage treatment of the city of Moscow" at the symposium in the USA)*

| **Slide Nos.** | Slide description |
|---|---|
| 1. | Sewerage scheme of the city of Moscow |
| 2. | Diagram "Sewerage development of the city of Moscow" |
| 3. | Diagram "Sewage treatment at treatment plants" |
| 4. | Figures for degree of sewage purification |
| 5. | Plan of facilities of the Kuryanovskaya activated sludge plant |
| 6. | Facilities of the I-st unit of the Kuryanovskaya activated sludge plant |
| 7. | Primary settling tanks of the I-st unit |
| 8. | Digestion tanks of the I-st unit (view of mechanical dewatering department) |
| 9. | Secondary settling tanks |
| 10. | Distribution chamber of the Novo-Kuryanovskaya activated sludge plant |
| 11. | Screens of the Novo-Kuryanovskaya activated sludge plant |
| 12. | Primary settling tanks of the Novo-Kuryanovskaya activated sludge plant |
| 13. | Aeration tanks of the Novo-Kuryanovskaya activated sludge plant |

14. Effluent outlet-contact channel
15. Control panel of the plant
16. Digestion tanks of the I-st unit of the Kuryanovskaya activated sludge plant
17. Digestion tanks of the Novo-Kuryanovskaya activated sludge plant
18. Vacuum filters
19. Drum dryers
20. Experimental filters for effluent polishing
21. Experimental unit of the treatment facilities
22. Activated sludge plant with a capacity of 50,000 m$^3$/day
23. Idem
24. Screen building
25. Long-term scheme of sewerage development
26. "Crystal" plant for treatment of waste water for automobile parks
27. Pumping station with a capacity of 800,000 m$^3$/day

# Protocol

of the fourth Meeting of the USSR and USA delegations on the problem of preventing Water Pollution from Industrial and Municipal Sources (Washington, D.C., USA, April 3-17, 1977).

In accordance with the Memorandum of the fifth Meeting of Joint USSR-USA Commission on Cooperation in the field of Environmental Protection (Moscow, November 1976), a Meeting of the USA-USSR delegations on the problem of waste water treatment took place from April 3-17, 1977.

The Soviet delegation was led by Yu. N. Andrianov, Director of the All-Union Association "Soyuzvodokanalniiproyekt".

The American delegation was led by Harold P. Cahill, Jr., Director, Municipal Construction Division, U.S. Environmental Protection Agency.

The participants of the Symposium were greeted by John T. Rhett, Deputy Assistant Administrator for Water Program Operations, U.S. Environmental Protection Agency.

A list of participants is attached as Appendix I.

During the meeting, the following was accomplished:

1. The Symposium on "Physical-Mechanical Waste Water Treatment Facilities".
2. Activities under the 1976 program of cooperation were discussed.
3. The Working Program for 1978 was coordinated and agreed upon.

## 1.

Thirteen scientific reports were presented at the Symposium: the Soviet delegation delivered six papers; the U.S. delegation seven. A list of these papers is attached as Appendix II.

Of particular interest were the Soviet papers on waste water treatment in flotation units, centrifuges, settling tanks and on waste water treatment in the City of Moscow, and American reports on waste water sedimentation, filtration, and the development of combined facilities.

The delegations have mutually agreed that each side will publish all the reports presented at the Symposium in the necessary number of copies in its own language prior to February 1, 1978, and will distribute them among interested organizations. Both sides will exchange ten copies each of the published Proceedings of the Symposium.

## 2.

During the Meeting the specialists actively discussed the results of current research conducted in accordance with the program for cooperation, and exchanged scientific and technical literature.

## 3.

The delegations determined and coordinated the joint cooperative work program for 1978 (Appendix III). Both sides have agreed that the Fifth (5th) Symposium entitled, "Recycling Water Supply Systems and Reuse of Treated Water at Industrial Plants" will be held in the USSR September 11-27, 1977.
In preparation for the forthcoming Symposium, the following was agreed upon:

- Each side will present 5-7 scientific reports to the Symposium;
- Both sides will exchange these report titles prior to July 1, 1977;
- The texts of the reports will be exchanged in two copies in Russian and English, prior to August 15, 1977.

The delegations noted that it would be expedient to carry out a long-term exchange:

- of Soviet specialists in the USA on the problem of waste water treatment, and
- of American specialists in the USSR on the problems of waste water treatment and reuse of treated water.

MSD Chicago invited two Soviet specialists to visit for a period of 2-3 months to become familiar with waste water treatment technology, construction of the facilities and applied instrumentation. The specialists will be able to study scientific resarch and the work projects of various organizations and likewise actual working facilities located in other States. In order to better prepare for the exchange of specialists, both sides will exchange proposals and requests for the long-term exchange by June 1. The detailed exchange program will be agreed upon five months prior to the date of the participants' departure. This exchange will be carried out on the basis of equal and "receiving-side-pays" basis. The final dates and the length of exchange shall be agreed upon during this meeting of the delegations in Moscow in September 1977.

During this visit to the USA, the Soviet delegation visited significant industrial and municipal waste water treatment plants in the Cities of Schaumberg, Chicago, Illinois; Contra Costa, California; Richmond, California; San Francisco, California; Los Angeles, California; Pascagoula, Mississippi; and a number of research institutes in Cincinnati, Ohio: Los Angeles, San Francisco, California; and the US Environmental Protection Agency in the City of Washington, D.C.

Both sides expressed their satisfaction that the meeting was conducted on a highly scientific and technical level in an atmosphere of friendship and in a spirit of mutual understanding, thus contributing to the further development and strengthening of cooperation in the field of environmental protection.

This protocol was signed on April 16, 1977, in two copies, in Russian and English, both texts being equally authentic.

From the US Side:

**Harold P. Cahill, Jr.**
Chief of Delegation

From the Soviet Side:

**Yu N. Andrianov**
Chief of Delegation

# Appendix I

## List of Participants from the Soviet Side

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**James Grutsch**
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**Richard Sullivan**
*Associate Executive Director*
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**Elaine Fitzback**
*Soviet Project Coordinator*
Office of Research and Development
US Environmental Protection Agency
Washington, D.C.

# Appendix II

## List of Reports Presented at the USSR-USA Symposium "Physical-Mechanical Wastewater Treatment Facilities"

**From the USSR:**

Myasnikov, I. N., Ponomarev, V. G., Nechaev, A. P., Kedrov, Yu. V.
*Wastewater Treatment by Physical and Mechanical Methods.*

Myasnikov, I. N., Gandurina, L. V., Butseva, L. N.
*Use of Flotation for Waste Water Treatment.*

Skirdov, I. V., Sidorova, I. A., Makimenko, Yu. L.
*Employment of Microstrainers in Waste Water Treatment Practice.*

Skirdov, I. V.
*Improvement of Hydraulic Conditions of Radial Settling Tanks.*

Pisanko, N. V.
*Waste Water Treatment in Mining, Metallurgical and Petrochemical Industries.*

Galanin, P. I.
*Sewage Treatment of the City of Moscow.*

**From the USA:**

Richard Field
*Swirl Separation or Flow Regulation and Solid Separation.*

Joseph A. Fitzpatrick
*Granular Media Filtration for Tertiary Application.*

John A. Oberteuffer, David M. Allen
*SALA-HGMSR Magnetic Filters to Treat Storm Overflows.*

James F. Grutsch
*Significant Parameters in Control of Physical/Mechanical Treatment of Refinery Waste Water.*

Frank Sebastian
*Pyrolysis Applications for Industrial and Municipal Treatment.*

Isaiah Gellman
*Current Status and Directions of Development of Physical/Mechanical Effluent Treatment in the Paper Industry.*

William J. Lacy
*Physical Treatment of Oil Refinery Waste Water.*

# Appendix III

## PROGRAM

### USSR-USA Cooperation of Working Group on Prevention of Water Pollution from Industrial and Municipal Sources

| NO | Title | Form of Work | Responsible for From the USSR | Responsible for From the USA | Time | Expected Results |
|---|---|---|---|---|---|---|
| 1. | Modernization of existing and development of new combined facilities with high efficiency for wastewater treatment, including hydrocyclones, multi-stage settlers, flotators, facilities with utilization of technical oxygen, investigations of usage of flocculants and coagulants. | Joint development of themes, scientific information and specialists delegation exchange. | VNII VODGEO GOSSTROY USSR | EPA | 1980 | Improvement of the efficiency of existing and development of new treatment facilities, reductions of space for location, reduction of reagents and cost price of waste water treatment. |
| | | Symposium on "The Use of Advanced Facilities and Equipment for Waste water Treatment (USA, Cincinnati, Ohio, April 2-16, 1978; eight specialists) | | | | |
| | | Symposium on theme: "Experiences with Electro-Chemical Wastewater Treatment Methods and their Further Development." (USSR, Moscow, September 10-24, 1978, eight specialists). | | | | |
| — | Development of hydrocyclones and pressure flotation facilities | | VNII VODGEO | | 1980 | Recommendations on designing hydrocyclones and pressure flotation facilities. |
| — | Development of tubular and plate settlers. | | | EPA | 1980 | Recommendations on applying settling tanks in waste water treatment. |
| — | Development of enriched oxygen systems for aeration. | | | EPA | 1980 | Development of open aeration tanks using technical oxygen. |
| — | Development of pure oxygen system aeration. | | VNII VODGEO | | 1980 | Development of covered aeration tanks using pure oxygen. |
| — | Development of filters with mixed sand and gravel media. | | VNII VODGEO | | 1979 | Recommendations on designing filters for wastewater treatment and final treatment. |
| — | Development of multi-media filters and equipment for continuous washing. | | | EPA | 1979 | Recommendations on development of multimedia filters. |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2. | Advanced technological wastewater treatment processes in petrochemical, chemical, petroleum refining, pulp and paper industries. | Information and delegation exchange | VNII VODGEO<br>GOSSTROY<br>USSR | EPA | 1979 | Upgrading wastewater treatment efficiency of existing treatment plants, introduction of new treatment schemes, maximum reuse of treated effluents. |
| — | Advanced technological wastewater treatment processes in petroleum refining industries. | | VNII VODGEO | | 1979 | Development of flow diagrams for treatment system using mechanical physical-chemical and bio-chemical methods applicable to the petroleum refining industry. |
| — | Advanced technological wastewater treatment processes in petrochemical and pulp and paper industries. | | | | 1979 | Development of flow diagrams for treatment systems using chemical additions for the pulp and paper and petrochemical industries. |
| 3. | Development of the best available technology and facilities for removal of nutrients and treatment of municipal wastewaters; the industrial recycle and reuse of the treated wastewaters. | Joint development of themes, information and delegation exchange | VNII VODGEO<br>GOSSTROY<br>USSR | EPA | 1980 | Development of new treatment facilities for prevention of entrophication, and development of new advanced treatment systems. Aimed at closed loop systems, with by product recovery by industry. |
| — | Development of methods and facilities for removal of nitrogen compounds. | | VNII VODGEO | | | Development of recommendations on designing facilities. |
| — | Development of optimum schemes of facilities for removal of nutrients. | | | EPA | | Development of recommendations on designing facilities. |
| 4. | Treatment of wastewater sludges and residuals. | Information and delegation exchange | VNII VODGEO<br>GOSSTROY<br>USSR | EPA | 1980 | Reduction of cost of sludge and other residuals treatment, increasing of overall treatment facilities efficiency. |
| — | Stabilization and dewatering of wastewater sludges and residuals. | | VNII VODGEO | | | Recommendations on designing facilities for stabilization and dewatering of wastewater sludges and residuals. |
| — | Technology and facilities for heat treatment and utilization of wastewater sludges and residuals. | | | | | Recommendations on designing facilities for heat treatment and utilization of wastewater sludges and residuals. |

# Appendix IV

## Itinerary

For the Visit of the USSR Gosstroy Delegation to the U.S. on questions of prevention of water pollution from industrial and municipal effluents from April 3-17, 1977.

| | |
|---|---|
| Sunday, April 3 | Arrive in New York City |
| Monday, April 4 | Sightseeing in New York |
| Tuesday, April 5 | Symposium |
| Wednesday, April 6 | Symposium |
| Thursday, April 7 | Cincinnati Lab Tour. Leave for Schaumberg, Illinois |
| Friday, April 8 | Schaumberg, Illinois (H. J. Heinz Co.). Tour of Establishment for Treating Effluent From Food Industry. Visit to John E. Egan Water Reclamation Plant |
| Saturday, April 9 | San Francisco, California—Sightseeing |
| Sunday, April 10 | Sightseeing in San Francisco |
| Monday, April 11 | Visit Contra Costa Sewage Treatment Plant. Tour of Treatment Plants at a Petroleum Refinery. Leave for Los Angeles, California |
| Tuesday, April 12 | Arrive in Los Angeles, California. Visit to Jet Propulsion Laboratories on Sediment Pyrolysis, in the Orange County Area. Visit to Disneyland |
| Wednesday, April 13 | Travel Day. Leave for Pascagoula, Mississippi |
| Thursday, April 14 | Arrive in Pascagoula, Mississippi. Pet Food & Quaker Oats. Also Pascagoula Municipal Treatment Plant. Familiarization with the Process of Effluent Treatment in Feed Processing Enterprises. |
| Friday, April 15 | Leave for Washington, D.C. |
| Saturday, April 16 | Washington, D.C. (Shopping and Tour of D.C.). Signing the Protocol. Final Meeting. Leave for New York City |
| Sunday, April 17 | New York City<br>Depart for USSR |

# Appendix V

## Symposium Program

**Tuesday, April 5**

| | |
|---|---|
| 8:30 a.m. | Registration |
| 9:00 a.m. | Opening Remarks—John T. Rhett |
| 9:15 a.m. | Welcome—Dr. David G. Stephan |
| 9:30 a.m. | Sebastian, F. P., Lachtman, D. S., Kroneberger, G. K., Allen, T. D., (Envirotech), Pyrolysis Applications for Industrial and Municipal Treatment |
| 10:15 a.m. | Break |
| 10:30 a.m. | Myasnikov, I. N., Ponomaryev, V. G., Nechaev, A. P., and Kedrov, Yu. V., (VNII Vodgeo, Gosstroi USSR), Wastewater Treatment by Physical and Mechanical Methods |
| 11:15 a.m. | Lacy, William, (US EPA), Physical Treatment of Oil Refinery Wastewater |
| 12:00 noon | Discussion |
| 12:15 a.m. | Lunch |
| 1:30 p.m. | Skirdov, I. V., (Vodgeo), Improvement of Hydraulic Conditions of Radial Settling Tanks |
| 2:15 p.m. | Gellman, Isaiah, (NCASI, Pulp & Paper Industry, New York, New York), Current Status and Directions of Development of Physico-Mechanical Effluent Treatment in the Paper Industry |
| 3:00 p.m. | Break |
| 3:15 p.m. | Skirdov, I. V., Sidorova, I. A., Maksimenko, Yu. L., (USSR) Employment of Microstrainers in the Wastewater Treatment Practice |
| 4:00 p.m. | Grutsch, J. F., (American Oil Company, Indiana), The Control of Refinery Mechanical Wastewater Treatment Processes by Controlling the Zeta Potential |
| 4:45 p.m. | Discussion |
| 5:00 p.m. | Adjourn |

**Wednesday, April 6**

| | |
|---|---|
| 9:00 a.m. | Opening Remarks—Harold Cahill |
| 9:15 a.m. | Address—Francis T. Mayo |
| 9:30 a.m. | Oberteuffer, J. A. and Allen, D. M. (Sala Magnetics, Cambridge, Mass.), Combined Storm Overflow Treatment with Sala-HGMF® High Gradient Magnetic Filters |
| 10:15 a.m. | Break |
| 10:30 a.m. | Myasnikov, I. N., Gandurina, L. V., Butseva, L. N., (USSR), Use of Flotation for Wastewater Treatment |
| 11:15 a.m. | FitzPatrick, J. A., and Swanson, C. L., (Northwestern University, Evanston, Illinois), Performance Tests on Full-Scale Tertiary Granular Filters |
| 12:00 noon | Discussion |
| 12:15 p.m. | Lunch |
| 1:30 p.m. | Pisanko, N. V., (Ukrvodokanalproekt Institute, USSR) Sewage Treatment in Mining, Metallurgical and Oil-Chemical Industries |
| 2:15 p.m. | Fields, R., (US EPA), The Swirl Concentrator for Treating and Regulating Sewered (Separate and Combined) and Unsewered Flows |
| 3:00 p.m. | Break |
| 3:15 p.m. | Galanin, P. I., (USSR), Sewage Treatment of the City of Moscow |
| 4:00 p.m. | Discussion |
| 4:15 p.m. | Adjourn |